Lecture 1
Introduction to Electromagnetics

GEOL 4397: Electromagnetic Methods for Exploration
GEOL 6398: Special Problems

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UNIVERSITY of HOUSTON
YOU ARE THE PRIDE
EARTH AND ATMOSPHERIC SCIENCES

Agenda

- Fundamentals of Electromagnetics
- Example Applications
- Apps
- Course contents
- Grading policy

What is this class about?

- Introductory electromagnetic course focusing on fundamental concepts in electromagnetic explorations for undergraduates and interested graduate students.

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- Introductory electromagnetic course focusing on fundamental concepts in electromagnetic explorations for undergraduates and interested graduate students.

- Prerequisites:
  - Willingness to learn
  - Perseverance
  - Calculus
  - College physics

Electrical conductivity

- Electromagnetic methods are sensitive to electrical conductivity σ (Siemens/meter)

https://gpg.geosci.xyz/content/electromagnetics/electromagnetic_physical_properties.html

Electrical conductivity

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- The inverse of conductivity is electrical resistivity, ρ (ohm·meters)

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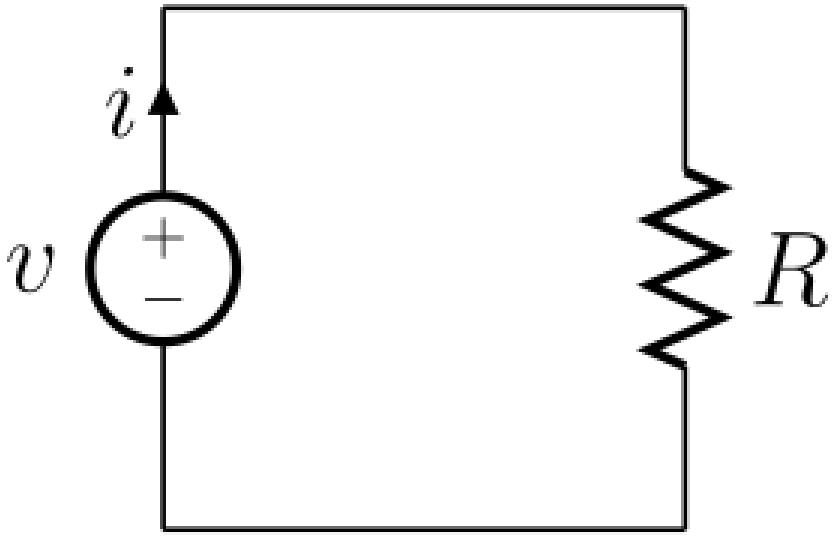
Electrical conductivity

- Electromagnetic methods are sensitive to electrical conductivity σ (Siemens/meter)
- The inverse of conductivity is electrical resistivity, ρ (ohm·meters)
- Electrical conductivity measures the ease that current flows through the materials when an electrical force is applied.

https://gpg.geosci.xyz/content/electromagnetics/electromagnetic_physical_properties.html

Electrical conductivity

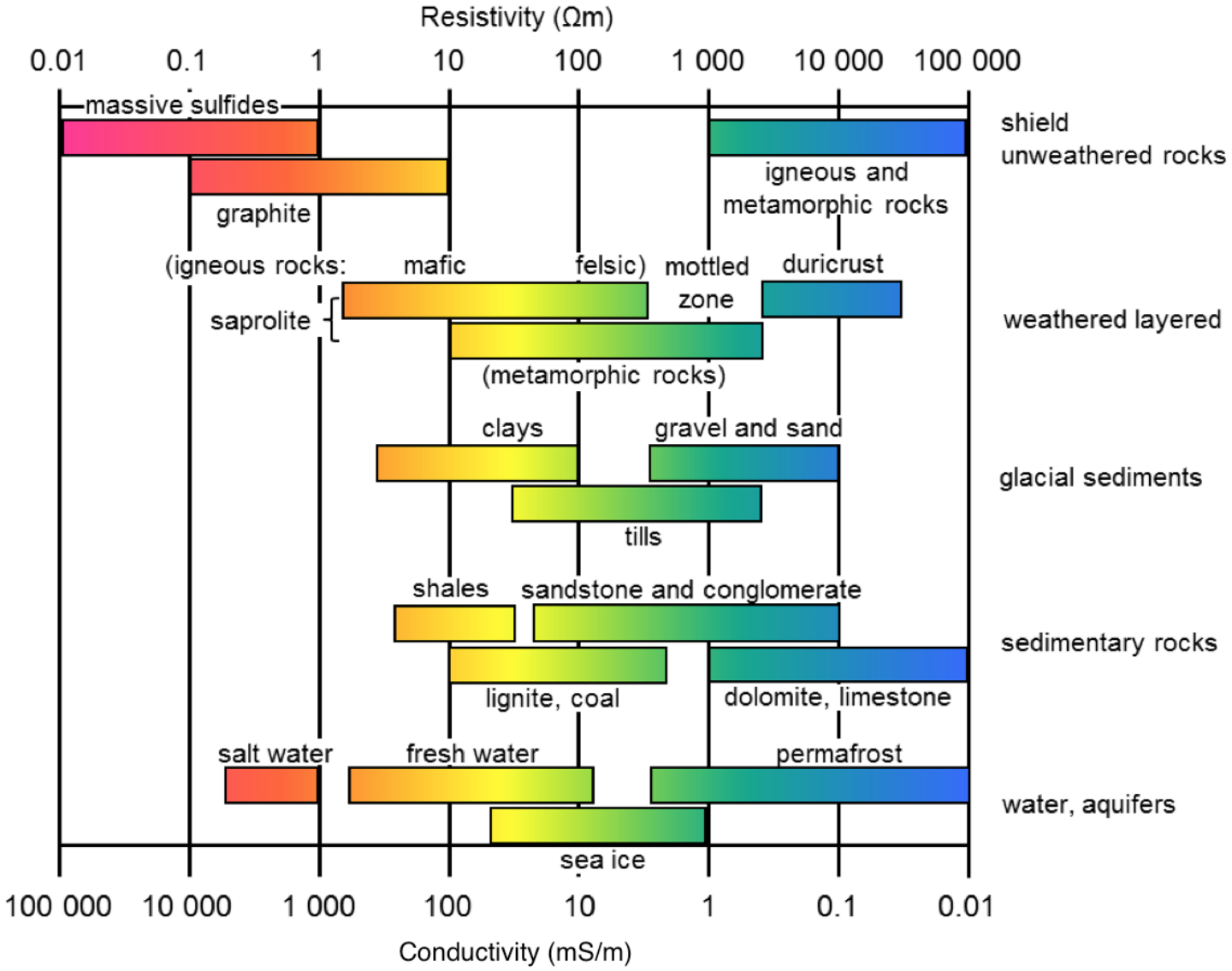


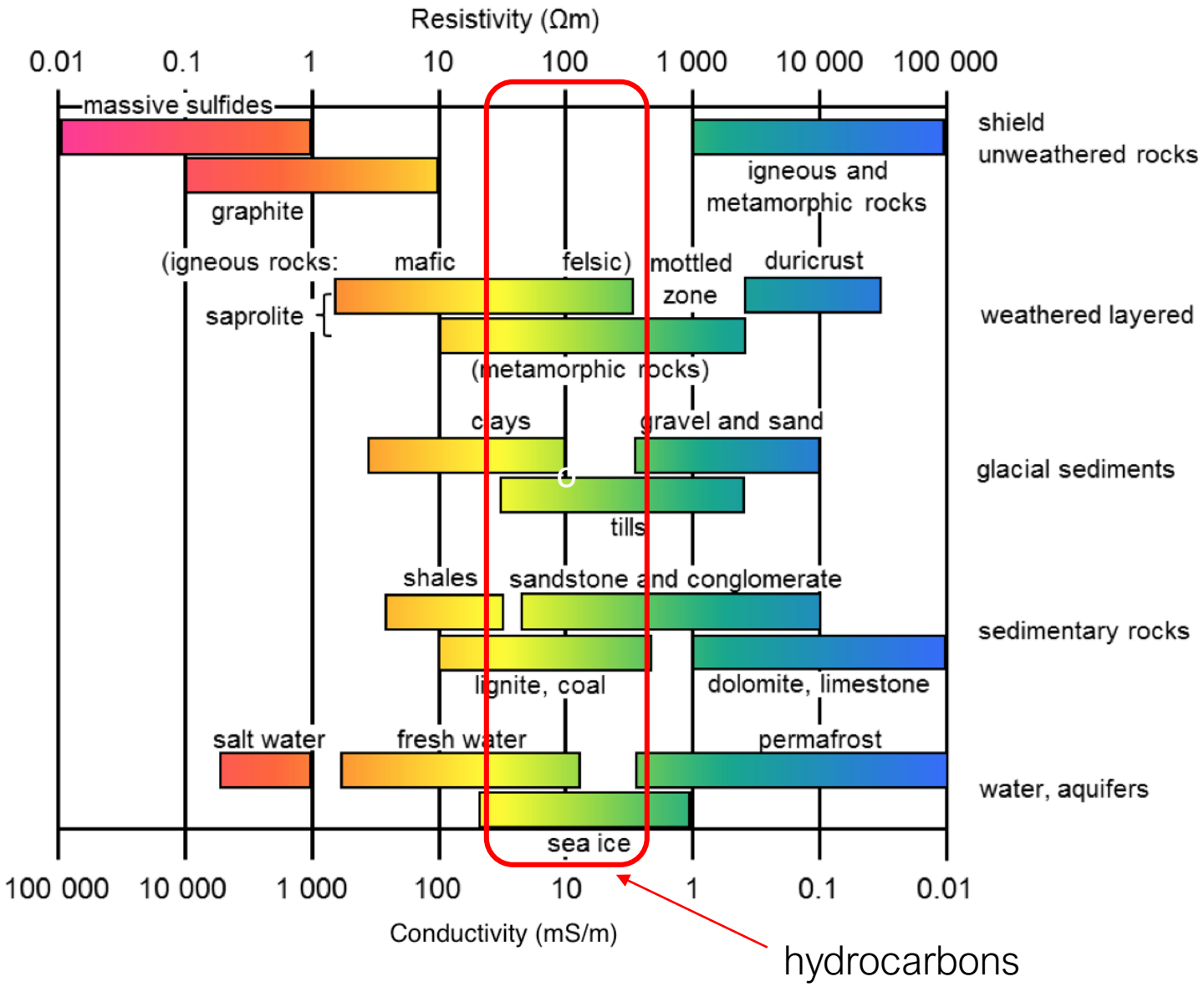
A simple electric circuit

Ohm's law

$$I = \frac{V}{R}$$

https://en.wikipedia.org/wiki/Electric_current


Resistivity (Ωm)
0.01
0.1
1
10
100
1 000
10 000
100 000
massive sulfides
graphite
igneous and metamorphic rocks
shield unweathered rocks
(igneous rocks: mafic felsic)
mottled zone
duricrust
saprolite
weathered layered
(metamorphic rocks)
clays
gravel and sand
glacial sediments
tills
shales
sandstone and conglomerate
sedimentary rocks
lignite, coal
dolomite, limestone
salt water
fresh water
permafrost
water, aquifers
sea ice
100 000
10 000
1 000
100
10
1
0.1
0.01
Conductivity (mS/m)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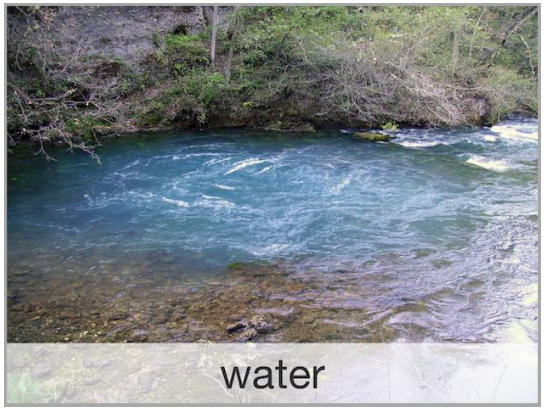
gravel and sand
tills
shales
sandstone and conglomerate
lignite, coal
dolomite, limestone
salt water
fresh water
permafrost
sea ice
shield unweathered rocks
igneous and metamorphic rocks
weathered layered
glacial sediments
sedimentary rocks
water, aquifers
100 000
10 000
1 000
100
10
1
0.1
0.01
Conductivity (mS/m)
hydrocarbons

Some applications

Electrical conductivity is diagnostic



Credit: Doug Oldenburg, Seogi Kang, Lindsey Heagy from UBC

Basic Principles

- Faraday's law

  A changing magnetic field will produce a voltage in a coil, causing currents to flow. This voltage is known as the induced electromotive force (EMF).

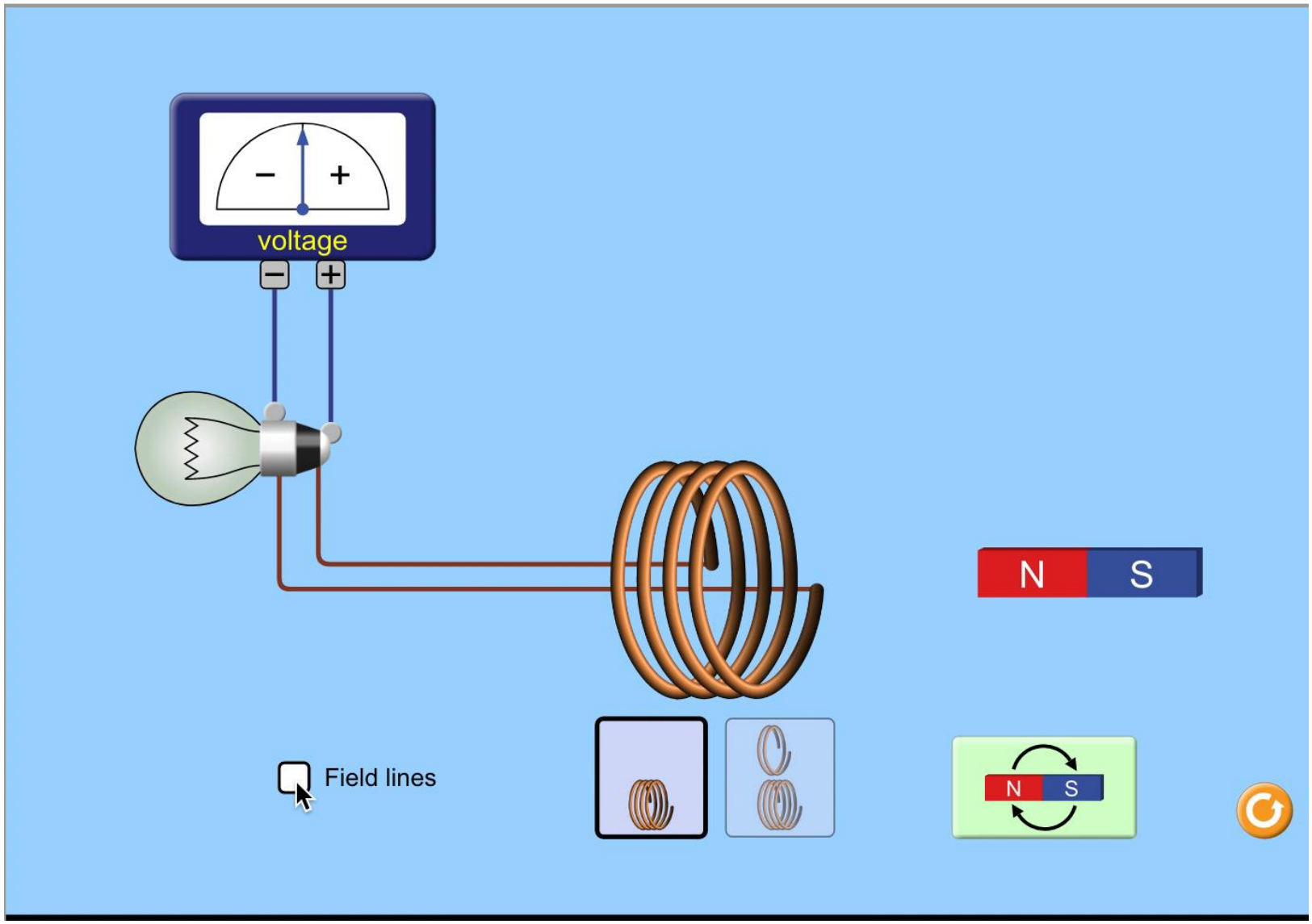
$$\nabla \times \mathbf{e} = -\frac{\partial \mathbf{b}}{\partial t}$$

- Ampere's law

  Electric currents generate magnetic fields.

$$\nabla \times \mathbf{h} = \mathbf{j} + \frac{\partial \mathbf{d}}{\partial t}$$

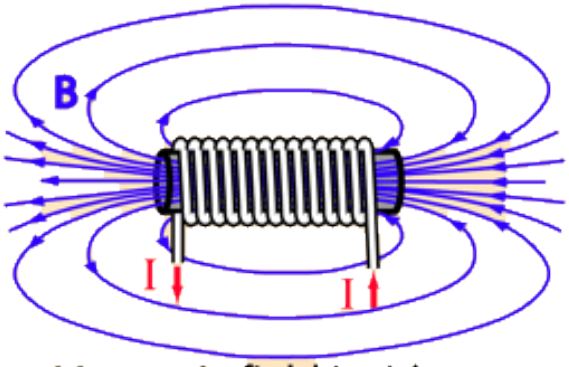
Faraday's Law



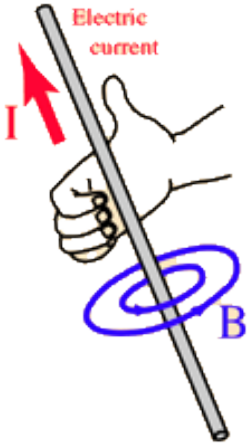
Faraday's law

- To explore more, go to https://gpg.geosci.xyz/content/electromagnetics/electromagnetic_basic_principles.html

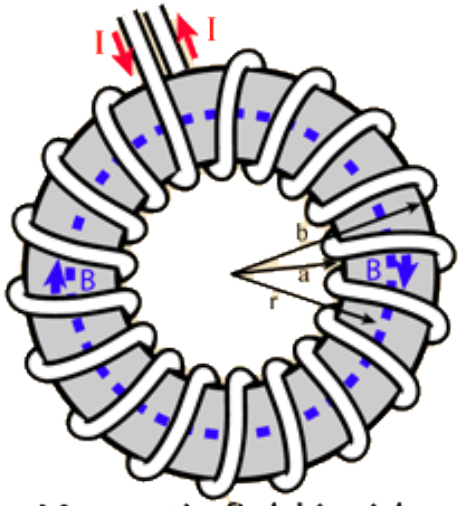
Ampere's law: examples



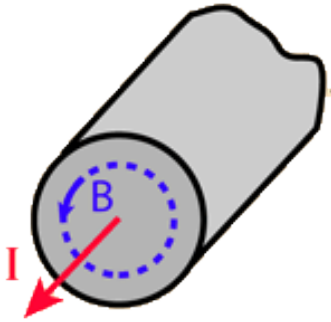
Magnetic field inside a long solenoic.



Magnetic field from a long straight wire.



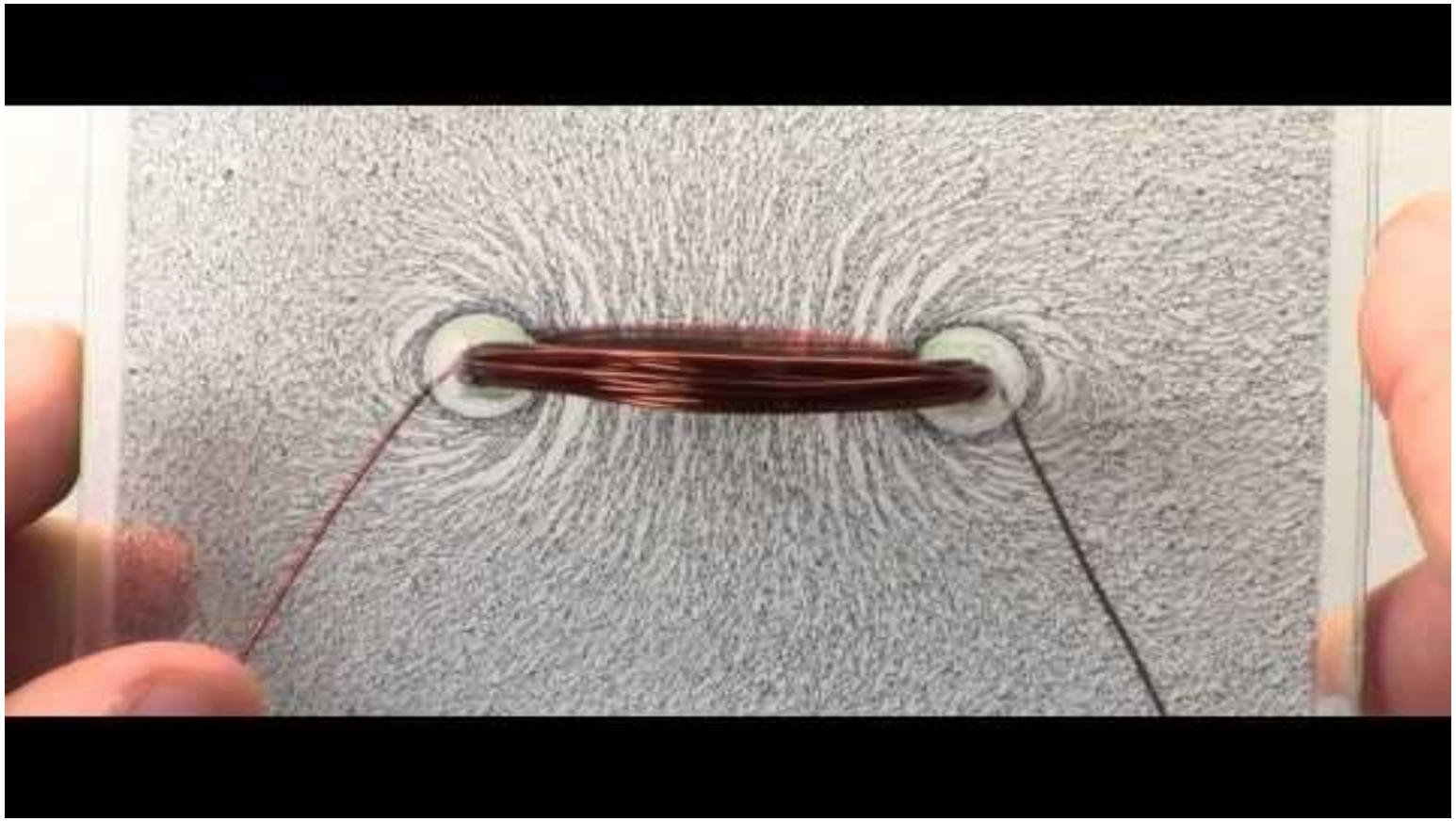
Magnetic field inside a toroidal coil.



Magnetic field inside a conductor.

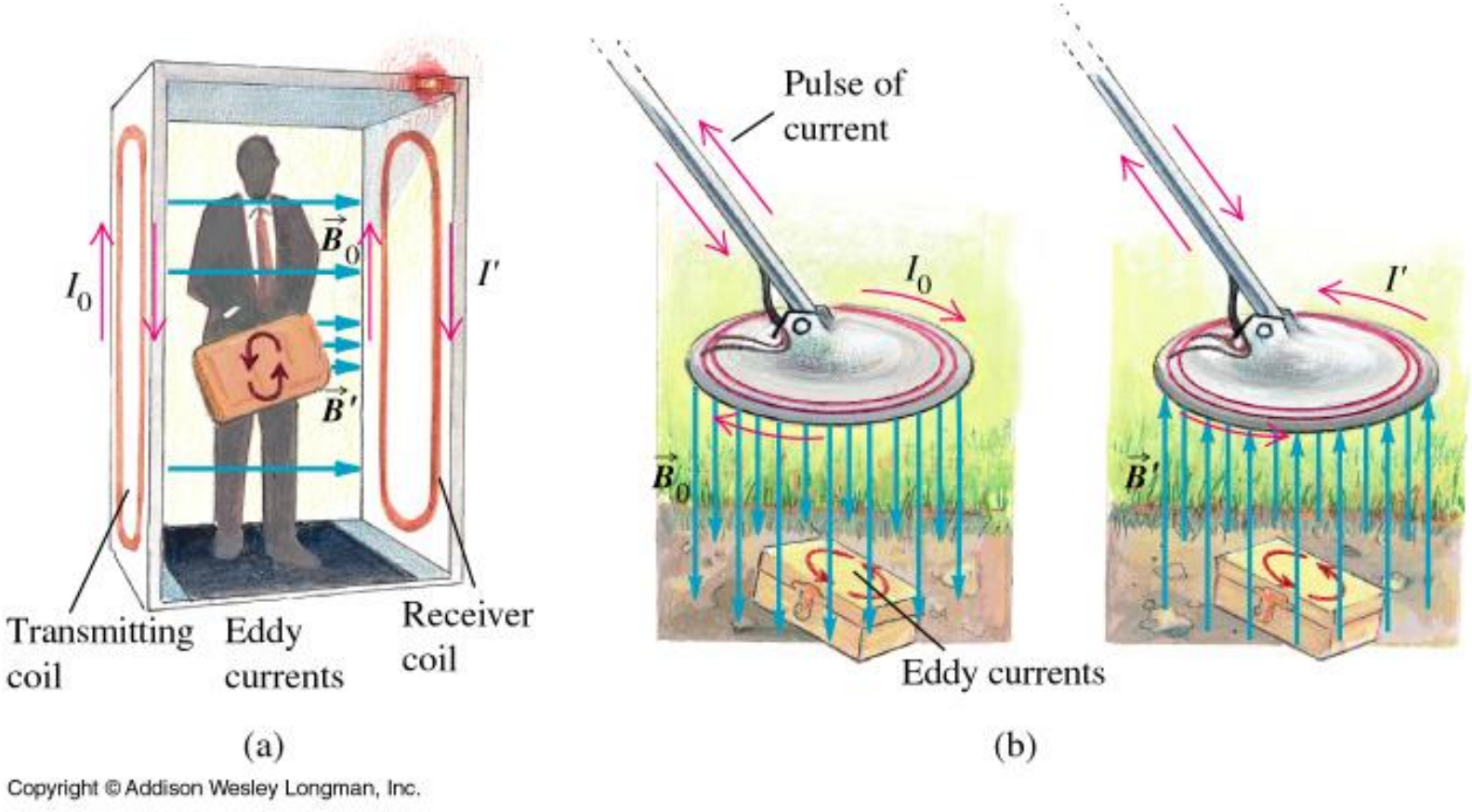
http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/amplaw.html

Magnetic field demonstrations using simple wire coils



Check out this video after class

Everyday example of EM induction



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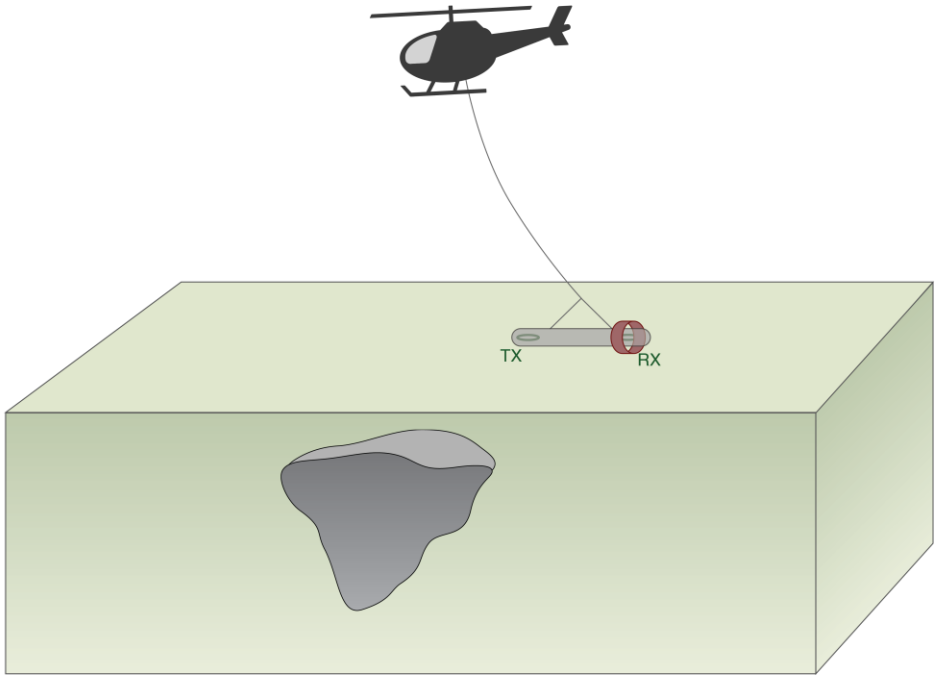
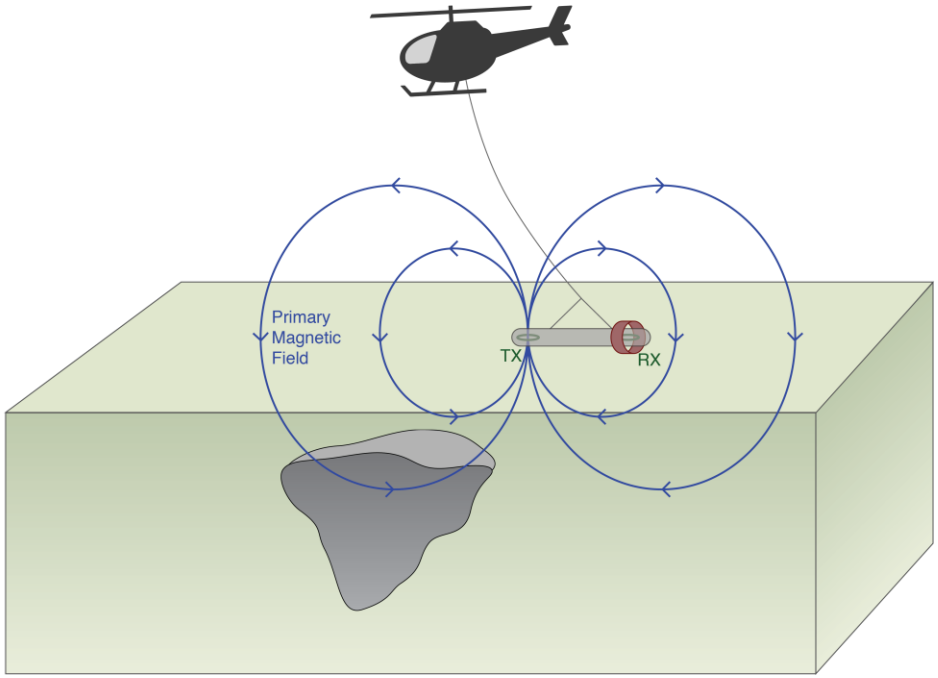
Basic Experiment

- Setup:
  - transmitter and receiver are in a towed bird



Basic Experiment

- **Setup:**
  - transmitter and receiver are in a towed bird
- **Primary:**
  - Transmitter produces a primary magnetic field



Basic Experiment

- **Setup:**
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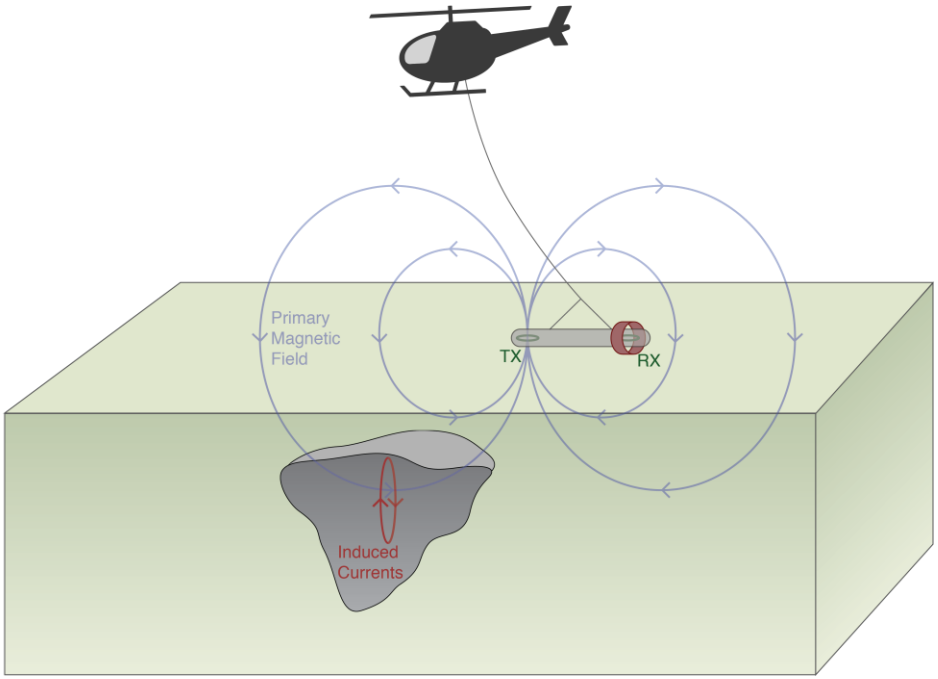
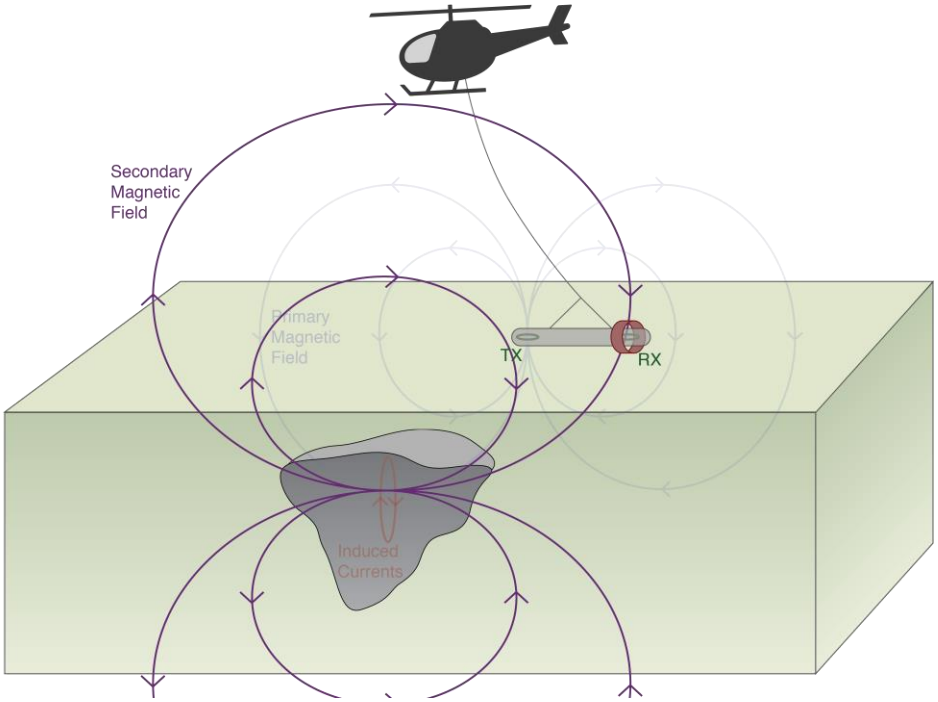
- **Induced Currents:**
  - Time varying magnetic fields generate electric fields everywhere and currents in conductors



Basic Experiment

- **Setup:**
  - transmitter and receiver are in a towed bird
- **Primary:**
  - Transmitter produces a primary magnetic field
- **Induced Currents:**
  - Time varying magnetic fields generate electric fields everywhere and currents in conductors
- **Secondary Fields:**
  - The induced currents produce a secondary magnetic field.



Agenda

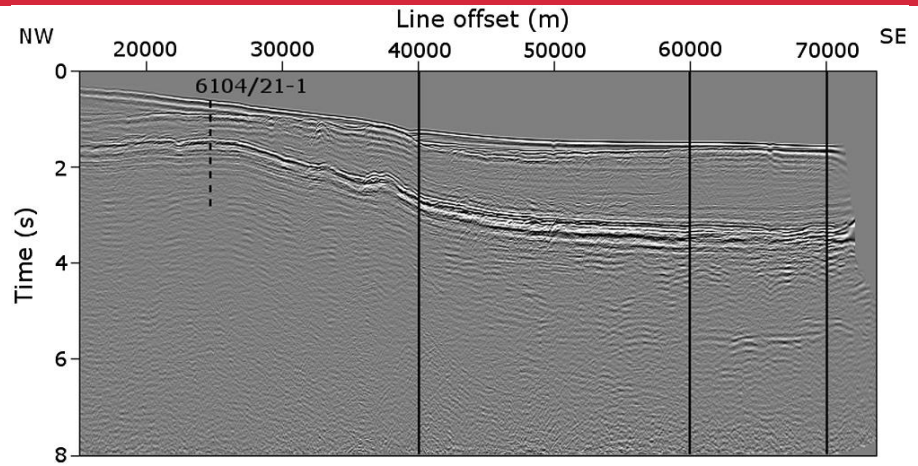
- Fundamentals of Electromagnetics
- Example Applications
- Web communications
- Course schedule
- Numerical modeling apps
- Grading policy

Sub-basalt imaging in Faroe-Shetland Basin

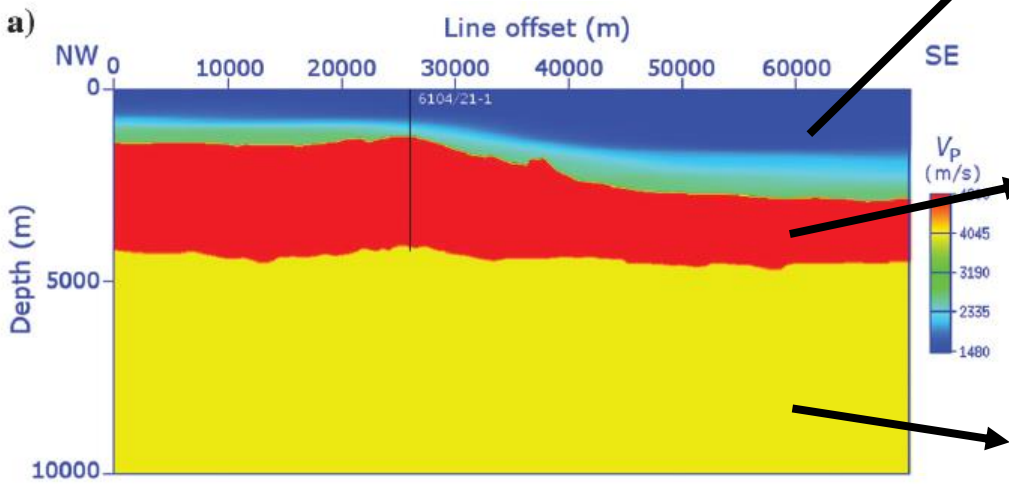
- Development of basin influenced by the breakup of North Atlantic, followed by extensive magmatism
- Extrusive igneous rock dominate the northwest margin of the basin
- Basalt sequence in the middle of the volcanic complex

Panzner et al. 2016

Seismic data



Time stack of the processed seismic data.



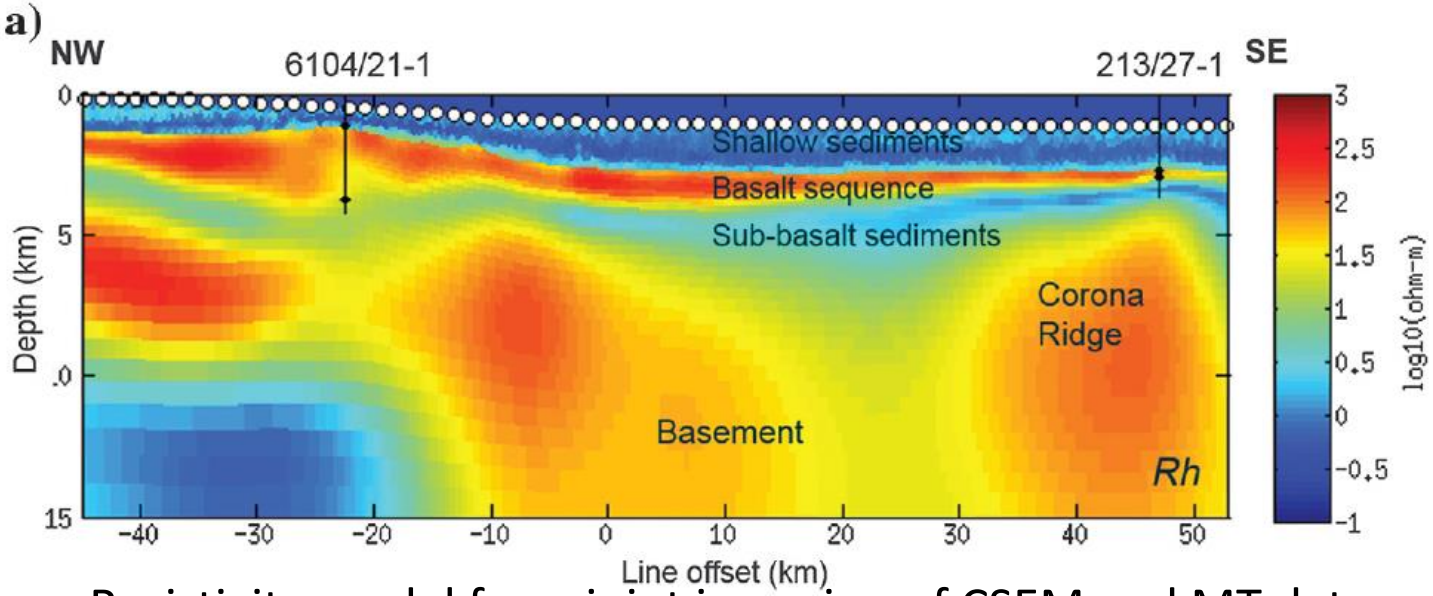
Velocity model from only seismic data

Suprabssalt sediments and the top of basalt are well constrained by data and well recovered.

Salt flooding applied to build velocity model below the top of basalt with constant velocity

Subbasalt reflections have small amplitudes contaminated by noise. 4000 m/s was chosen because of flat angle gathers

Panzner et al. 2016



Resistivity model from joint inversion of CSEM and MT data

Depth to the top of basalt from seismic data used as structural constraint for EM inversion.

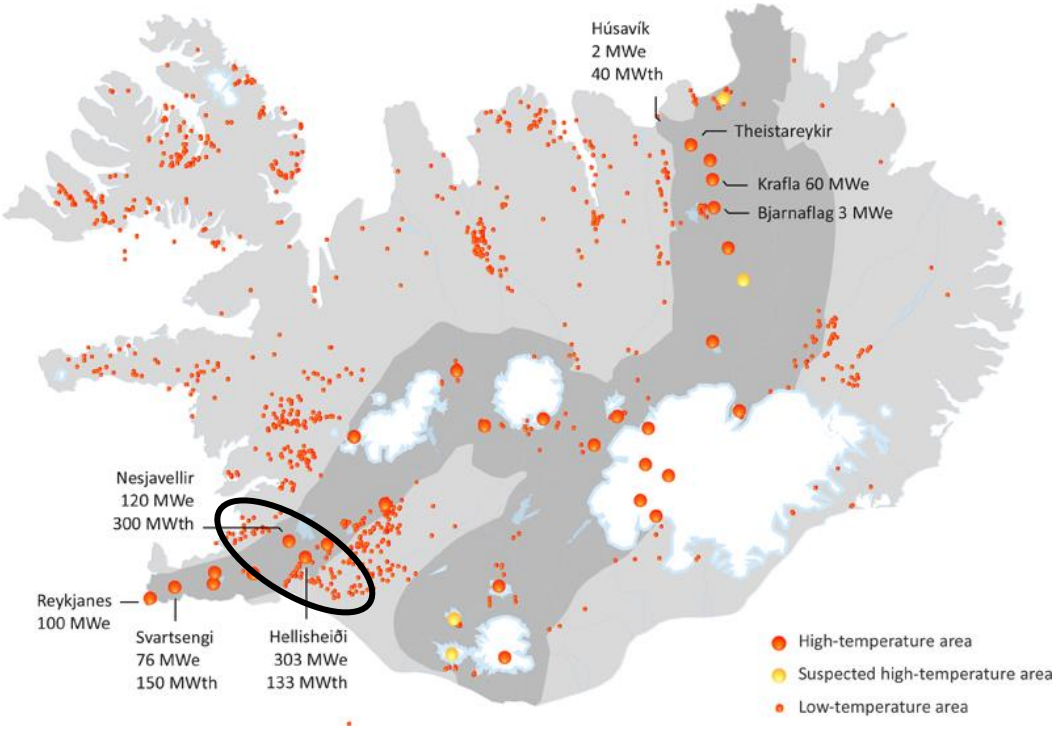
Good agreement between inversion and reported thickness of basalt sequence in the two wells.

Good agreement between inverted resistivities and measured ones in Brugdan well

Panzner et al. 2016

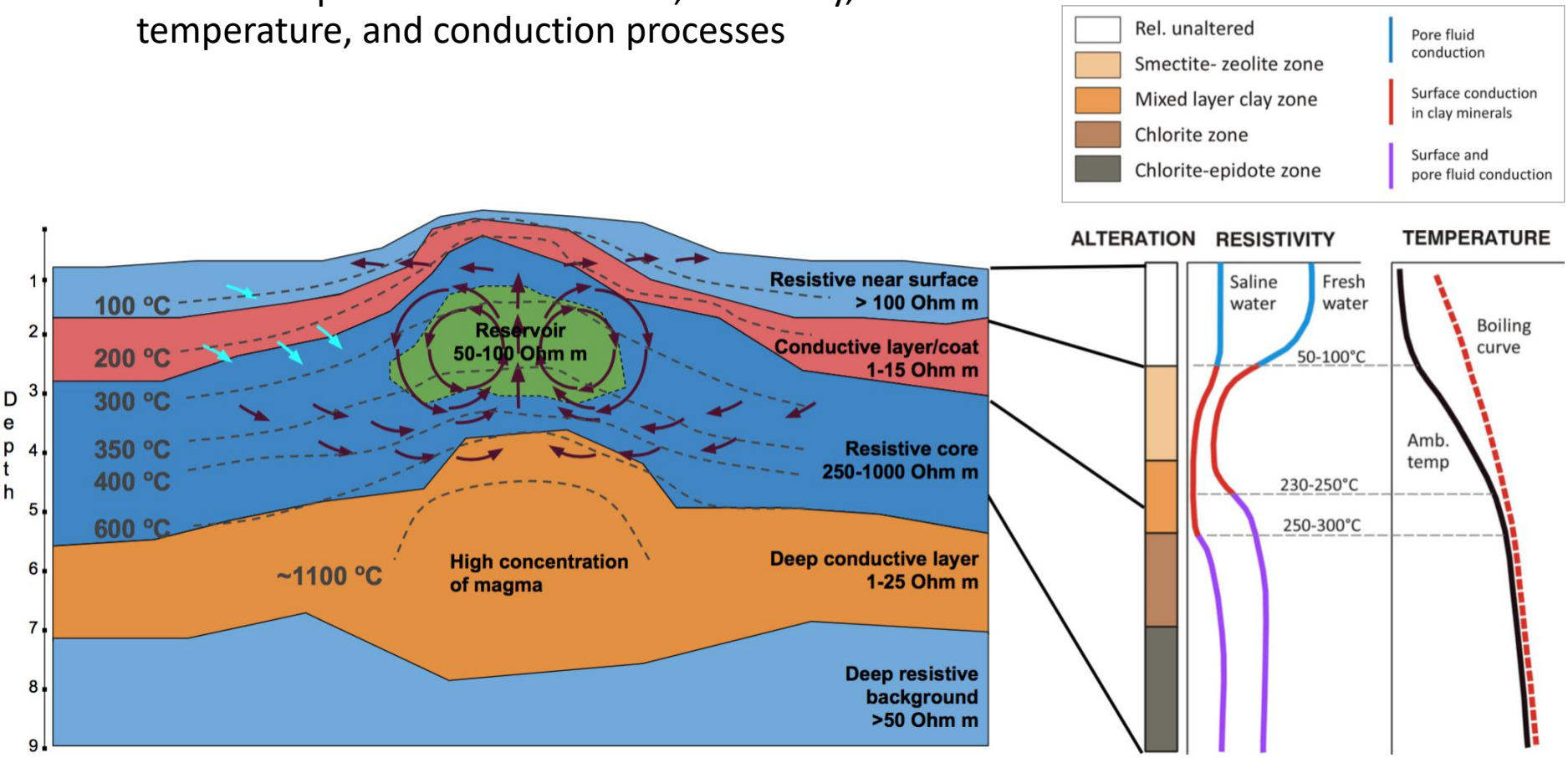
Hengill geothermal region: setup

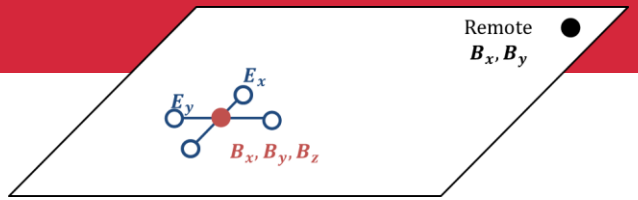
- Iceland: geothermal hot spot
  - On the mid-Atlantic ridge
  - Hosts multiple high temperature geothermal systems
- Hengill geothermal area
  - Supplies majority of hot water in Reykjavik
  - Contributes ~450 Mwe to National power grid



Physical properties

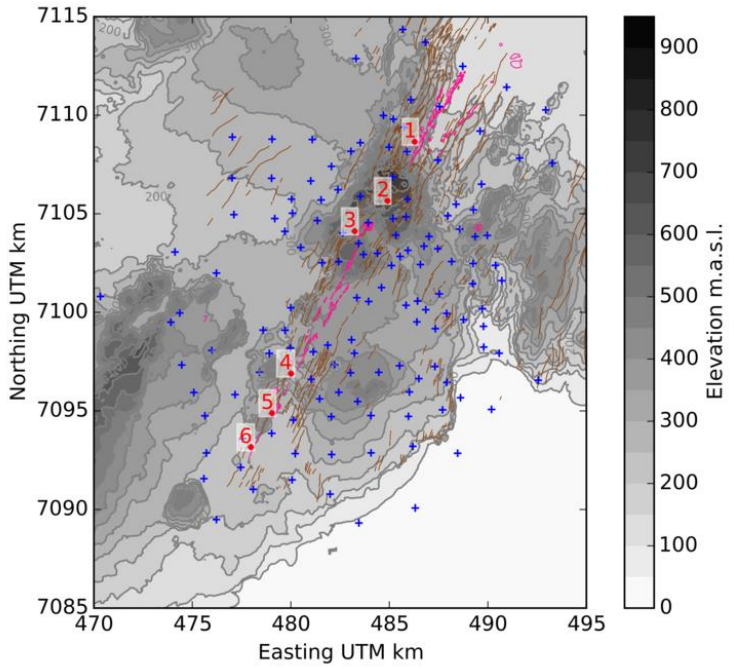
- Relationships between alteration, resistivity, temperature, and conduction processes





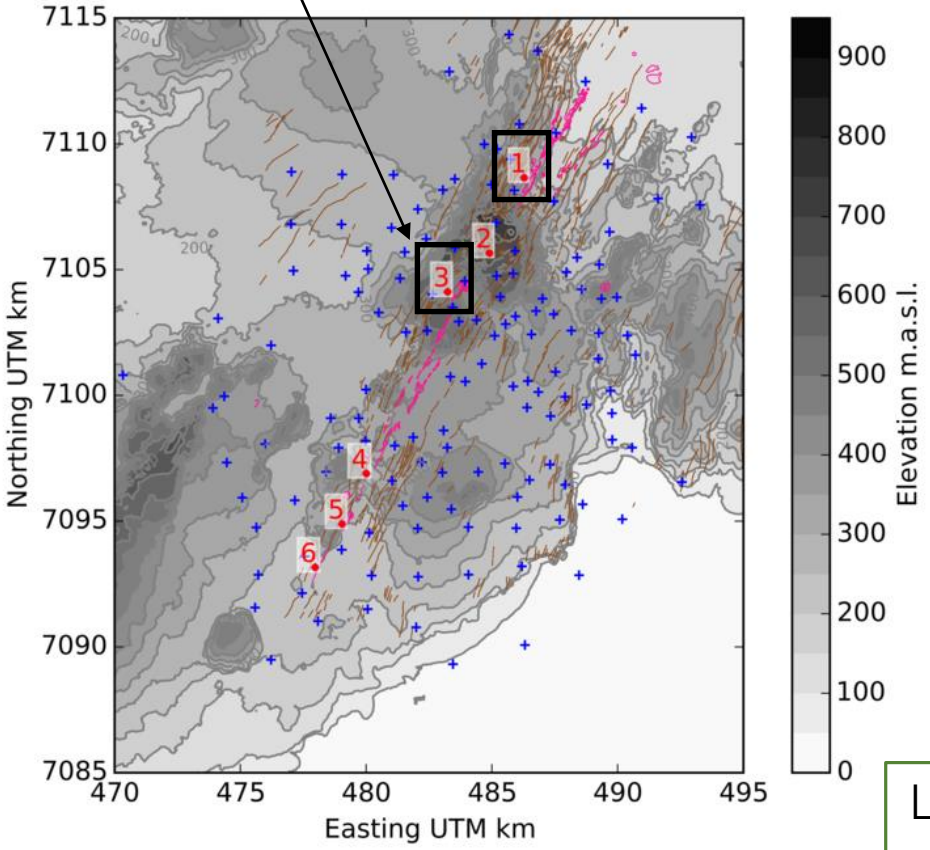
Survey

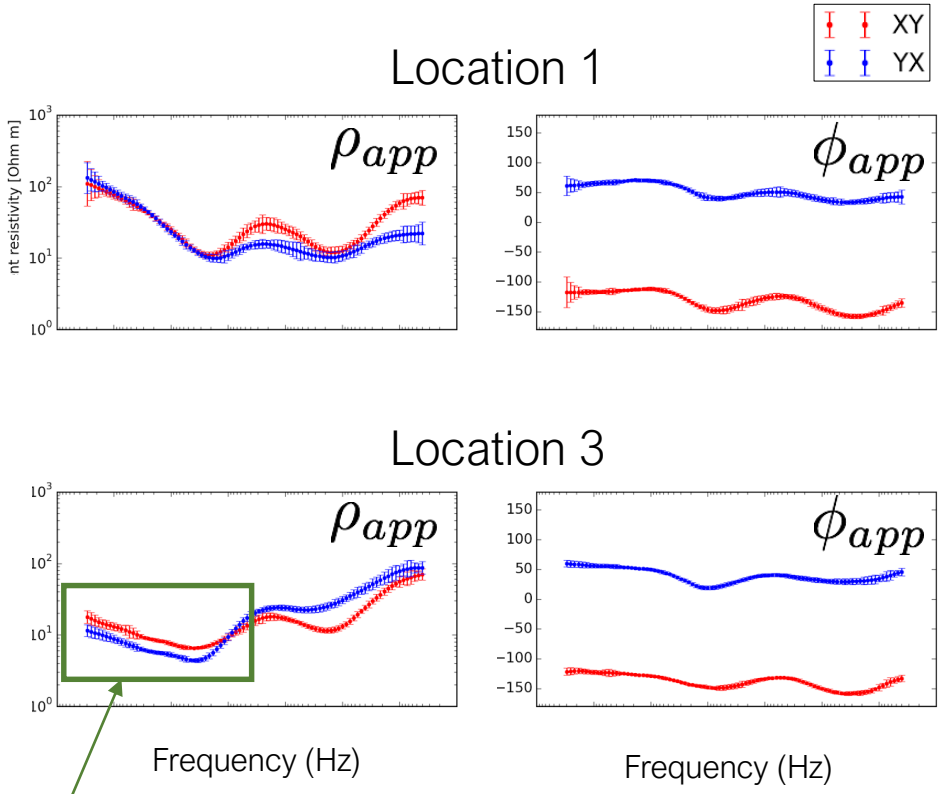
- MT instrumentation
  - Phoenix MTU5's
- Survey
  - 133 stations used
  - Combination of 2E and 2E+3H setup
  - Frequencies: 300 – 0.001 Hz
- Remote reference
  - About 40 km away
- Raw data processing using Phoenix software



Data

Surface alteration,
hot water, fumaroles

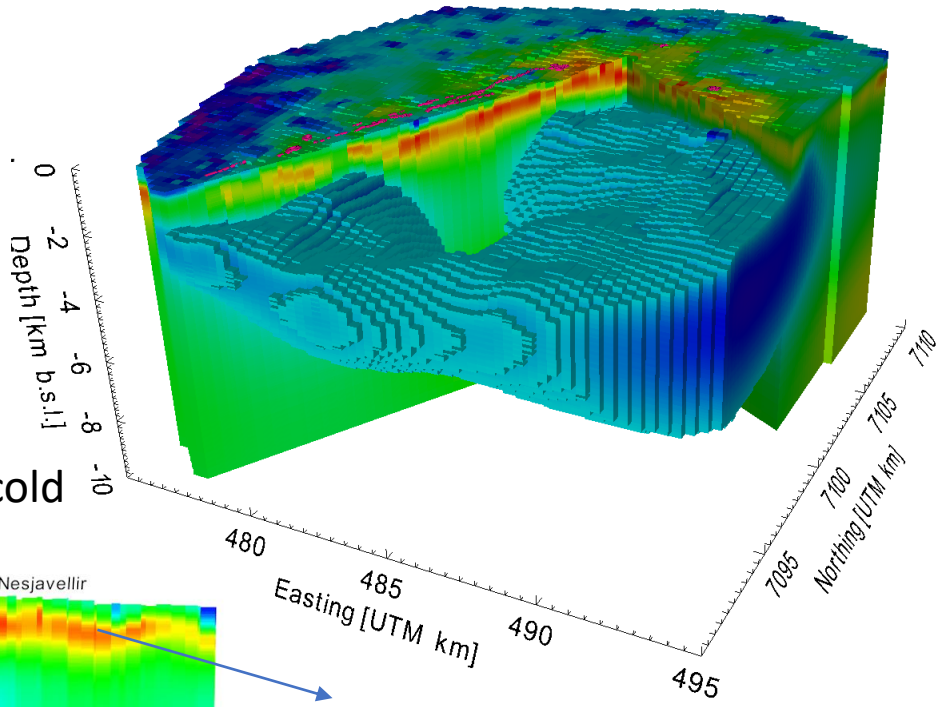


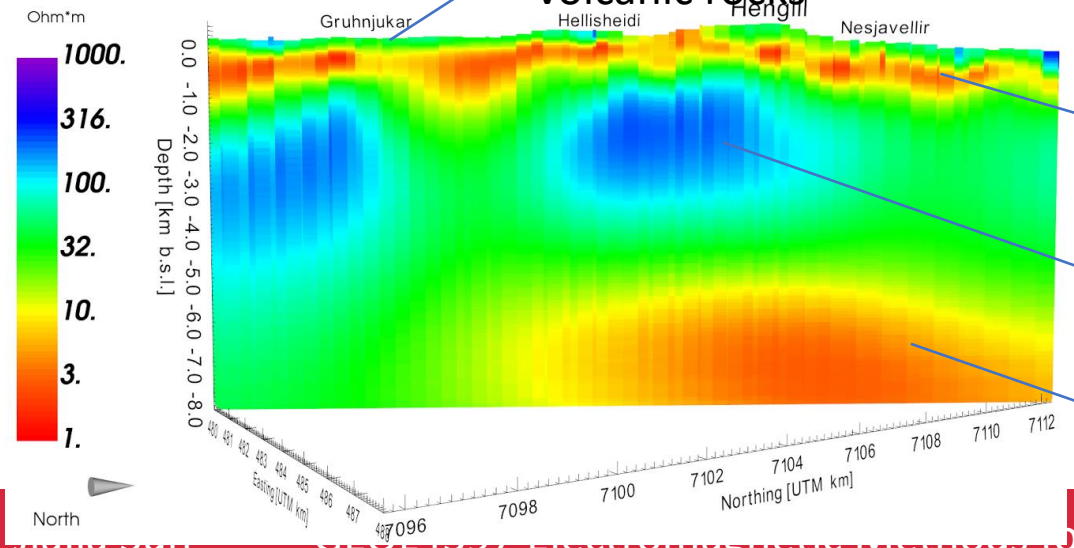


Low apparent resistivity

3D inversion

- Off-diagonal impedance (Z_{xy} and Z_{yx}) used
- Combined multi-frequency inversion (300 Hz – 0.001 Hz)





Unaltered and cold volcanic rocks

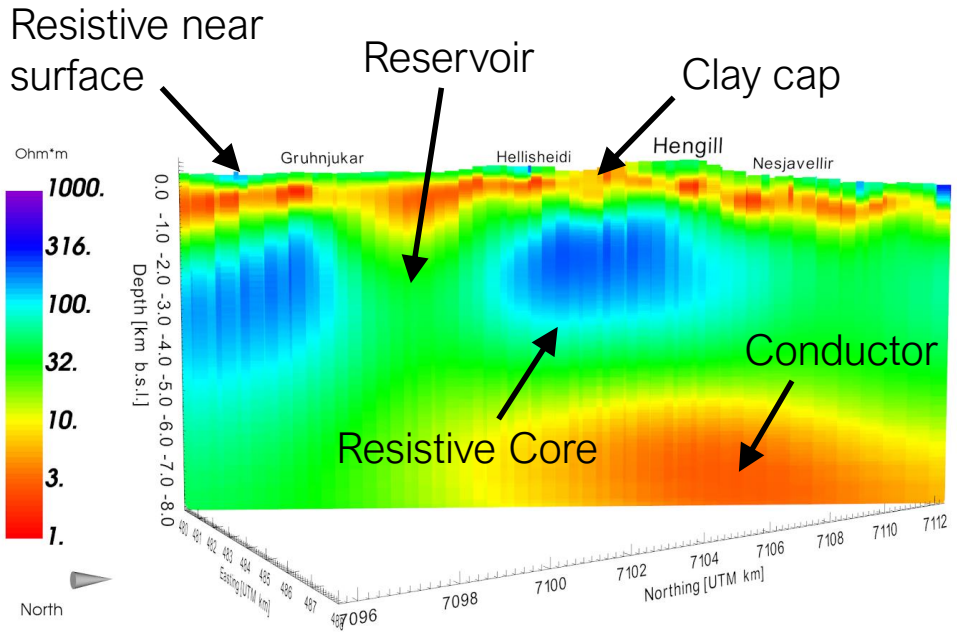
Smectite and zeolite hydrothermal alteration

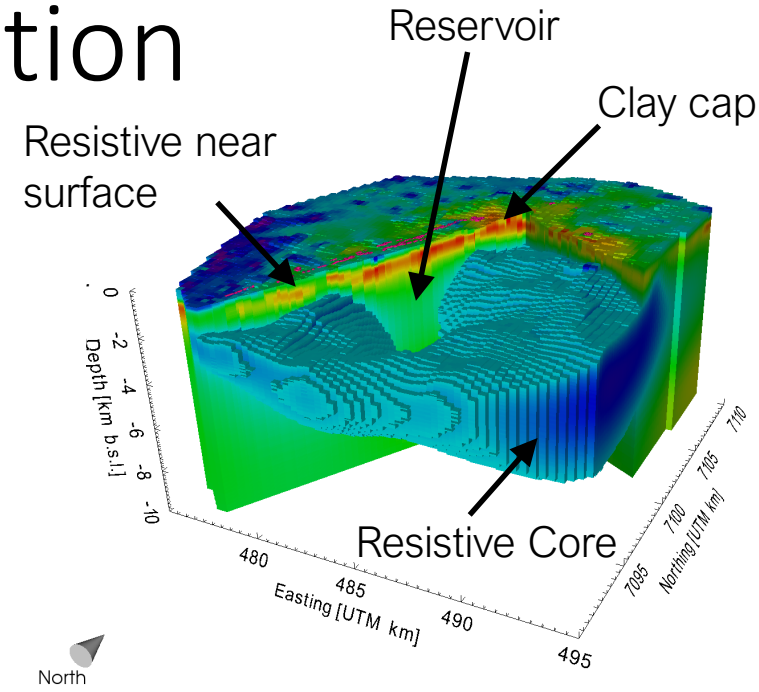
Chlorite and epidote alteration

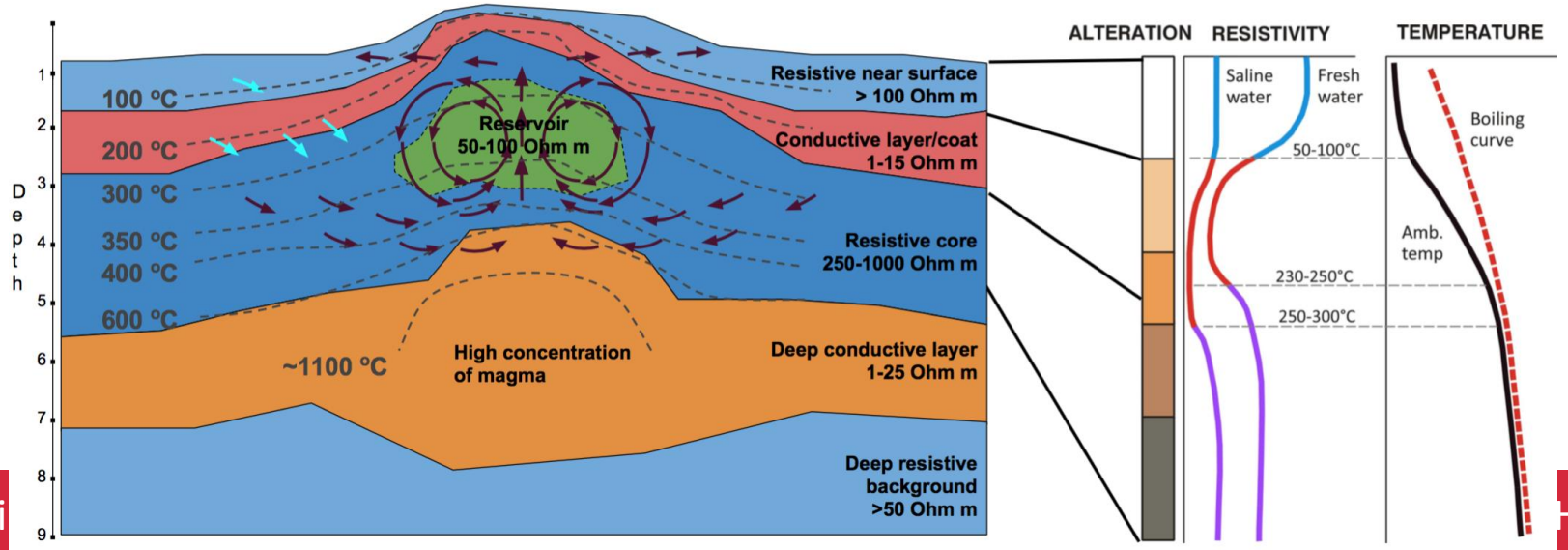
Heat source

Rosenkjaer et al, 2015

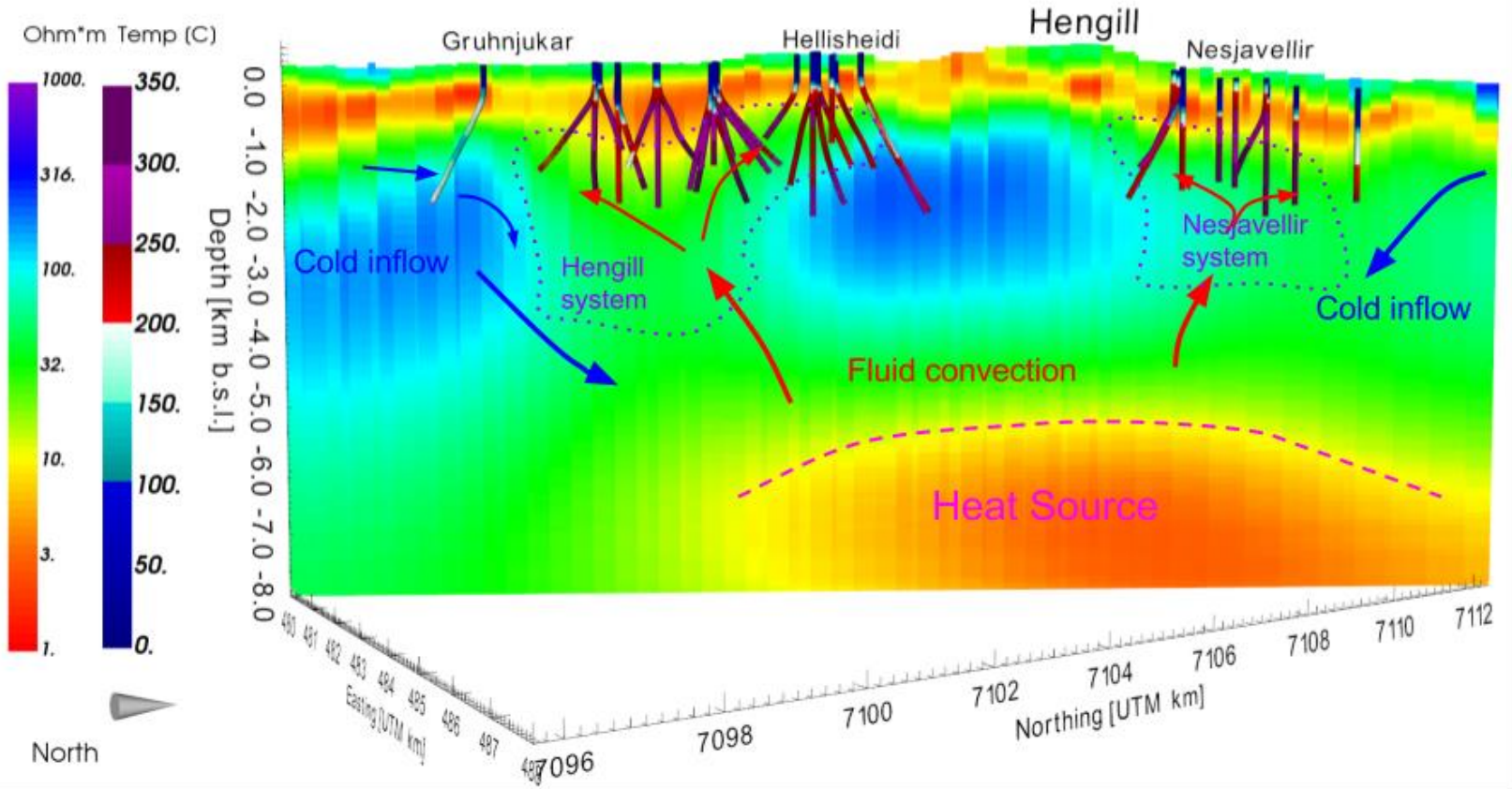
Interpretation





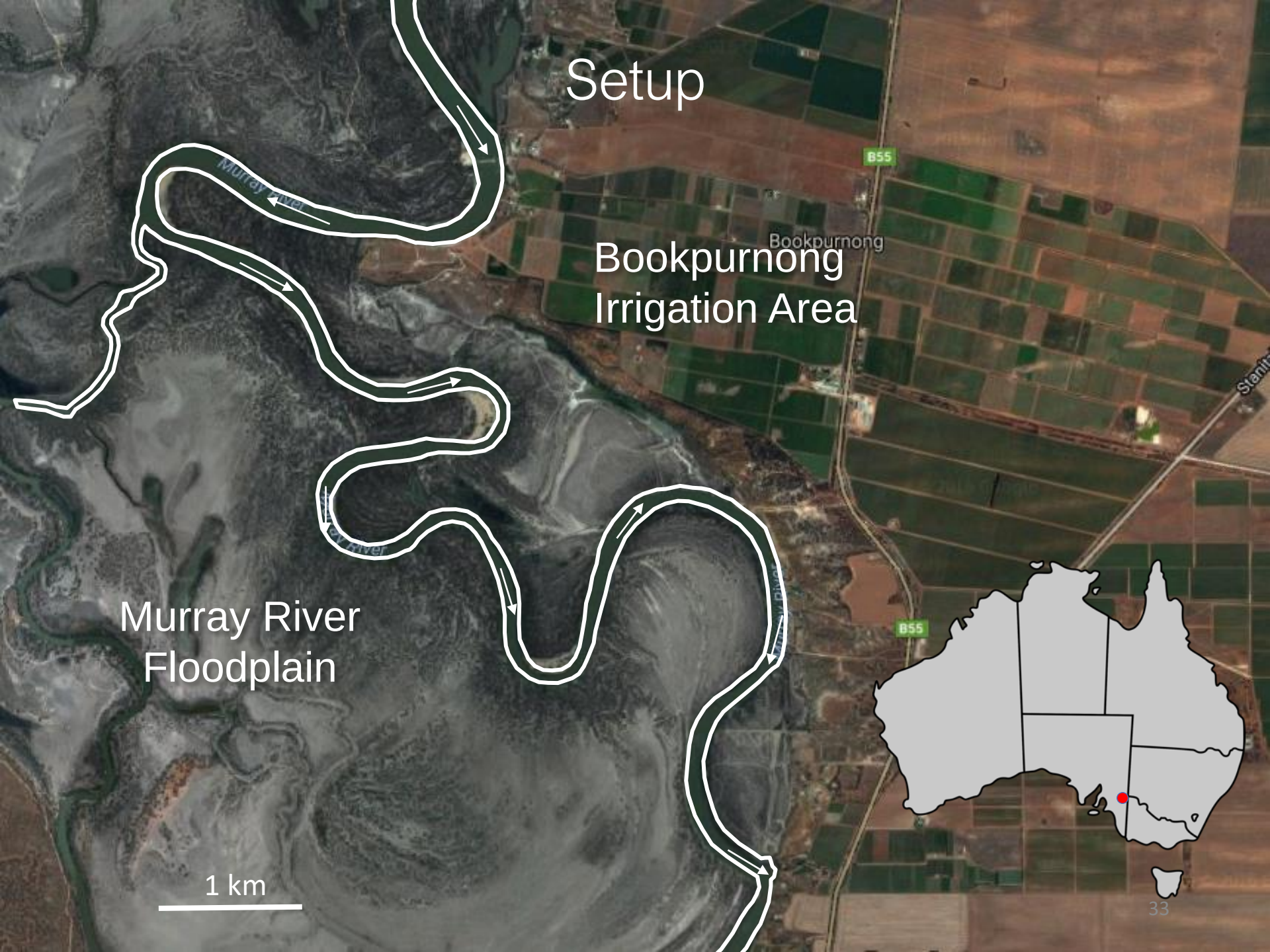


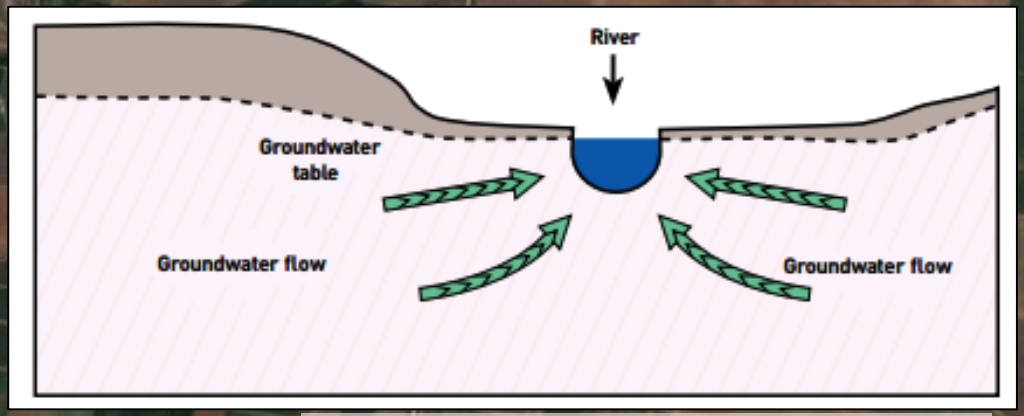
Synthesis



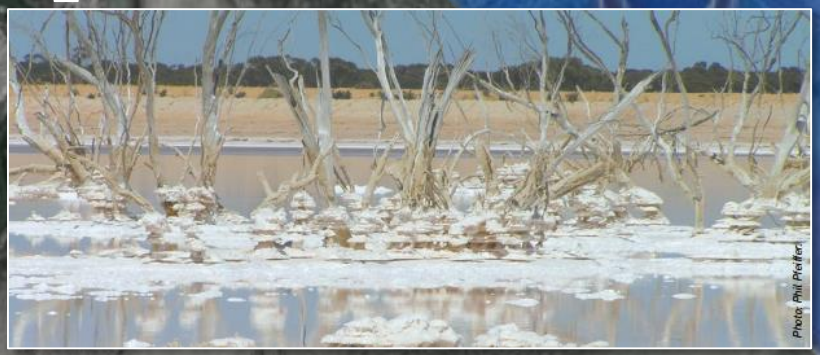
- Conductive layer corresponds with formation temperature
- Two main production fields: Hengill and Nesjavellir
- Deep conductive heat source

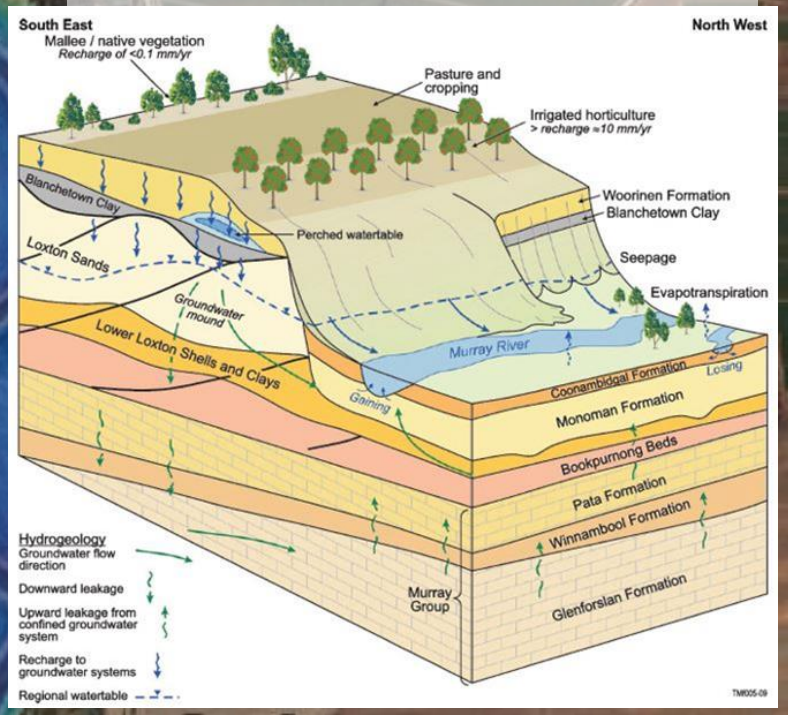
Setup


Bookpurnong
Irrigation Area
Murray River
Floodplain
1 km
B55
Bookpurnong

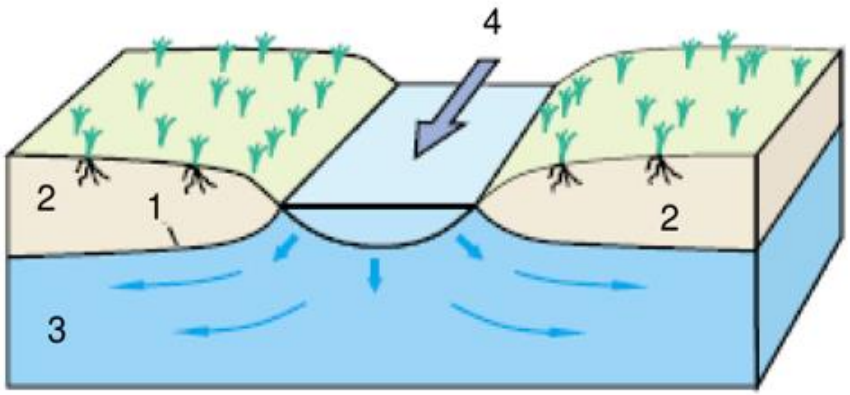


- over-irrigation and drought
- saline water recharges river
- floodplain salinization
- ecological damage

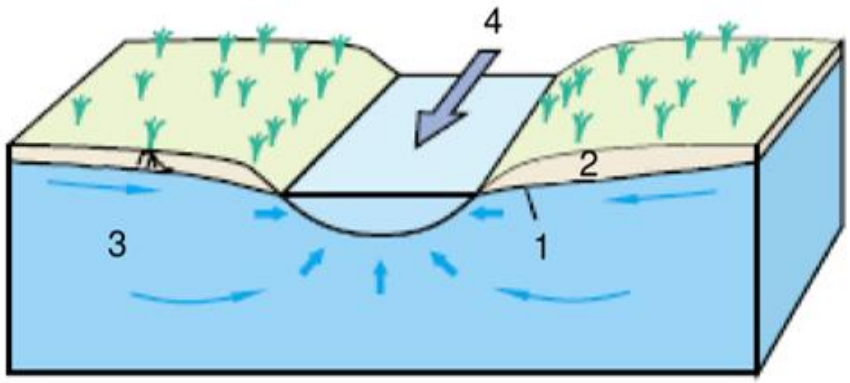




Losing Stream



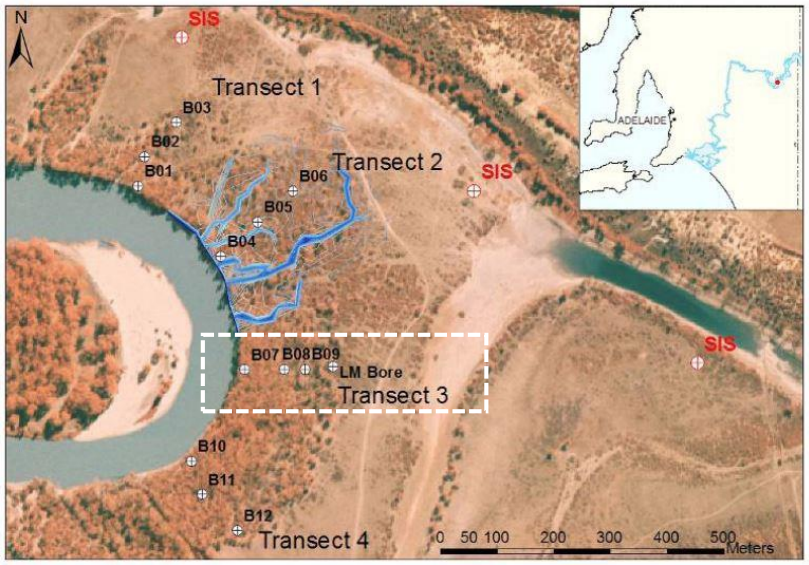
Gaining Stream



1 – Water table 2 – Unsaturated zone 3 – Saturated zone 4 – Flow direction

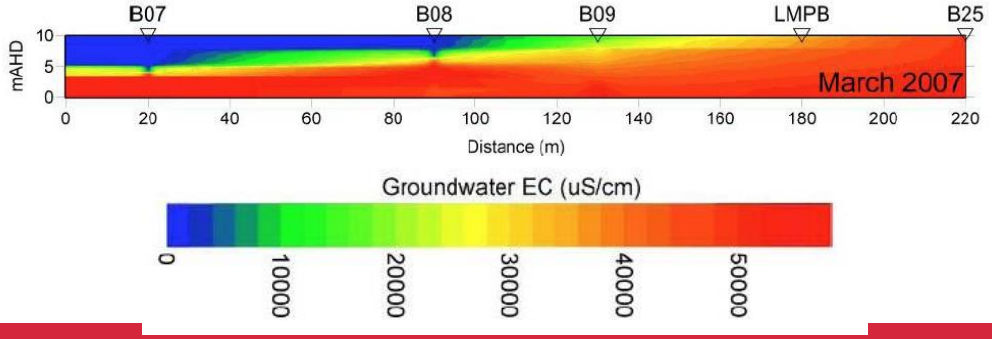
Properties

Location map for salinity measurements



Unit	Conductivity
Saline water	High, 3 - 5 S/m
Fresh water	Low, 0.01 S/m

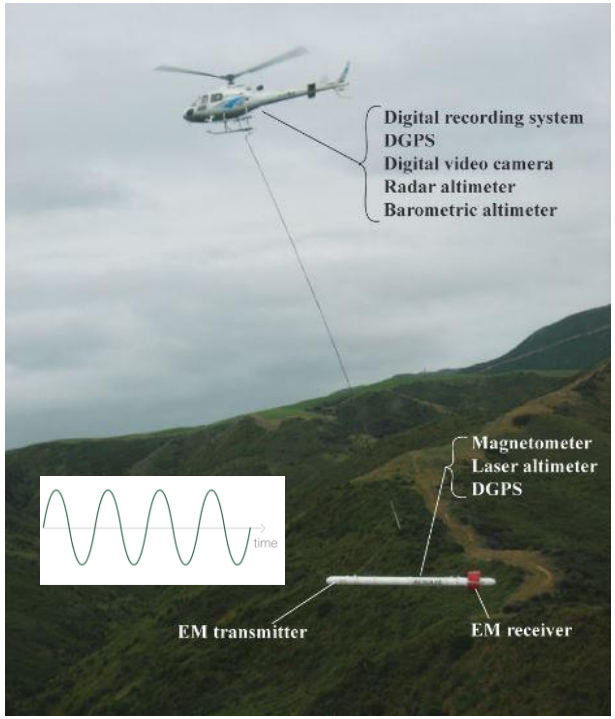
Conductivity from salinity measurements



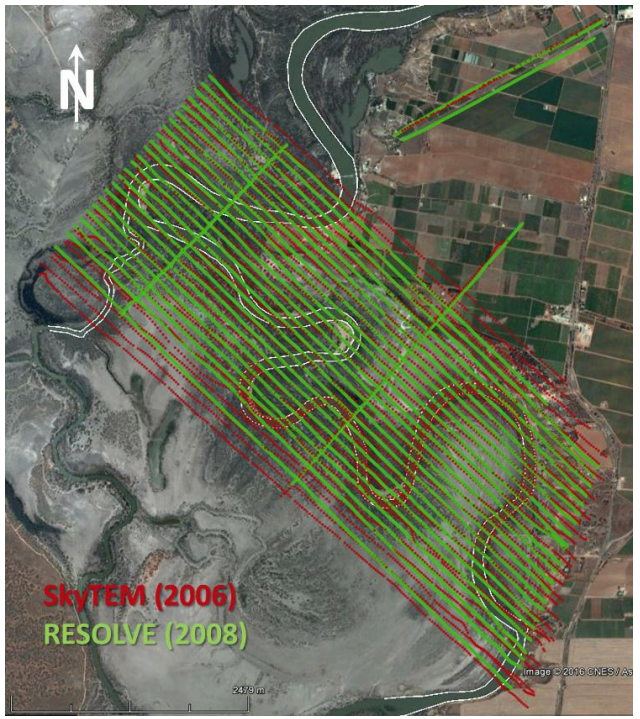
Holland et. al., 2008.

Survey

Resolve system (2008)



Flight lines



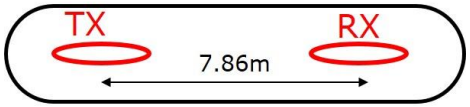
Horizontal Co-planar (HCP) frequencies:

- 382, 1822, 7970, 35920 and 130100 Hz

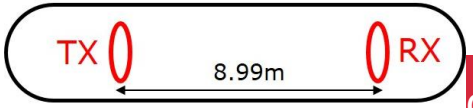
Vertical Co-axial (VCA) frequencies:

- 3258 Hz

Horizontal Co-planar



Vertical Co-axial

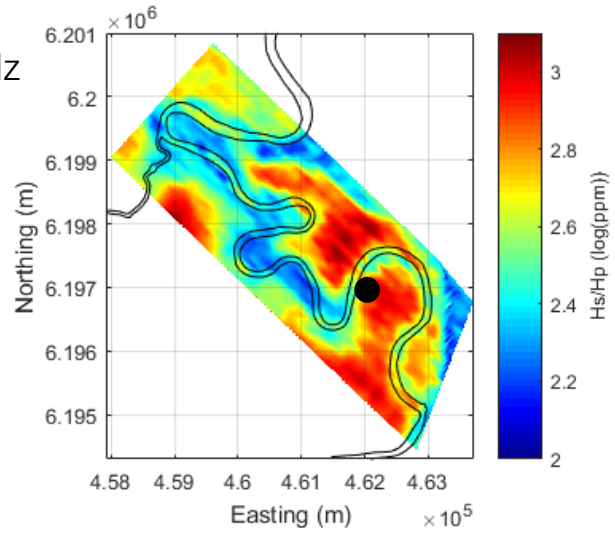


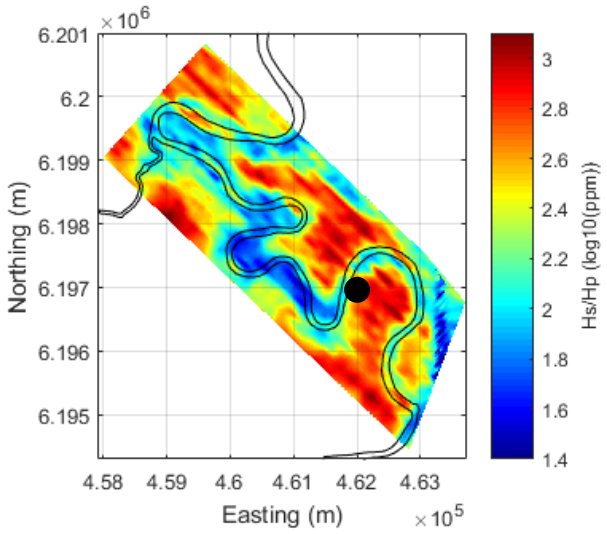
Horizontal Co-planar (HCP) data

In-Phase (Real)

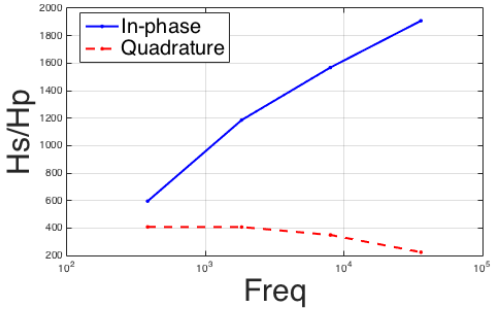
Quadrature (Imaginary)

382 Hz

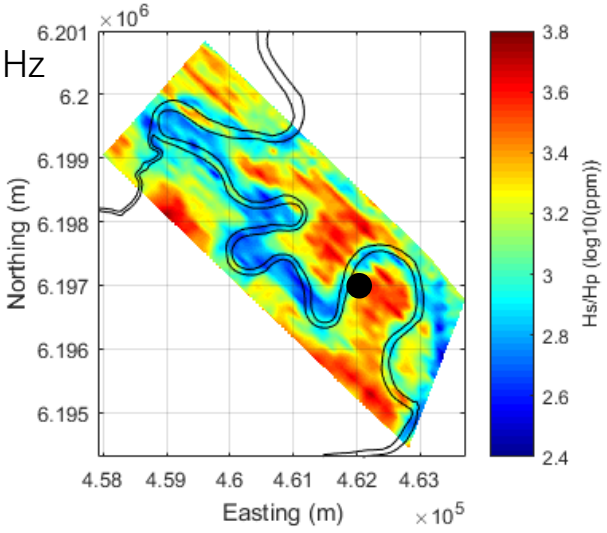


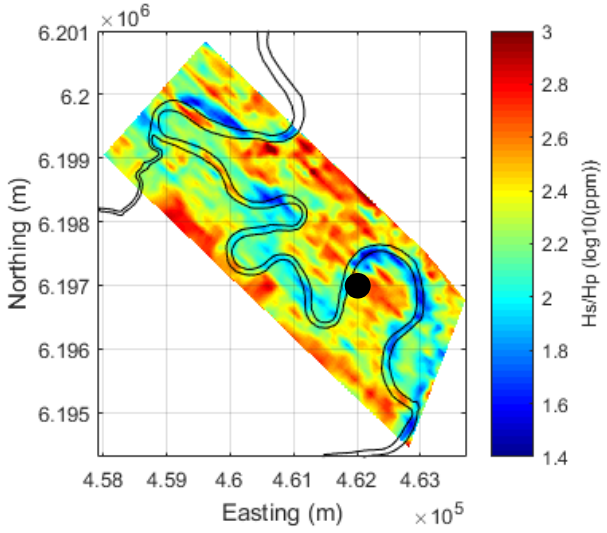


Sounding curve

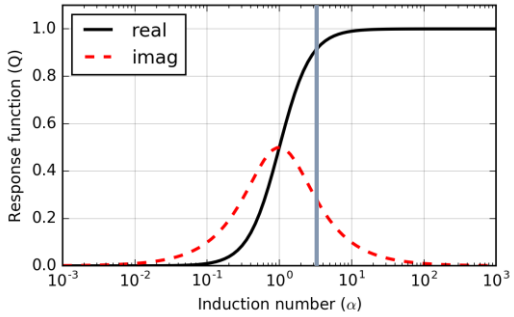


35920 Hz



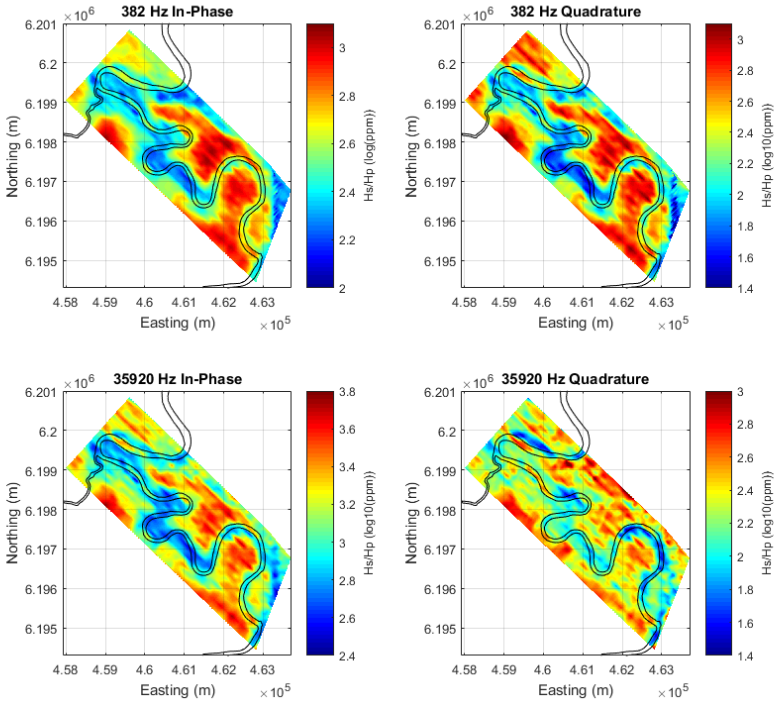


Response curve

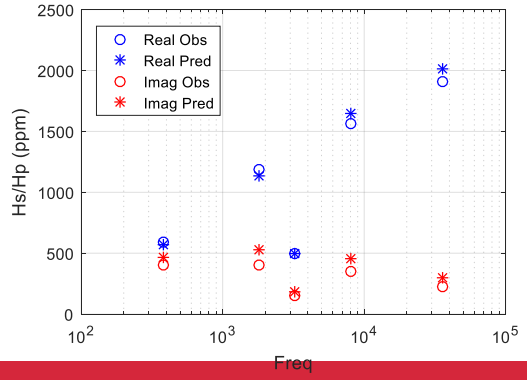


Processing: 1D inversion

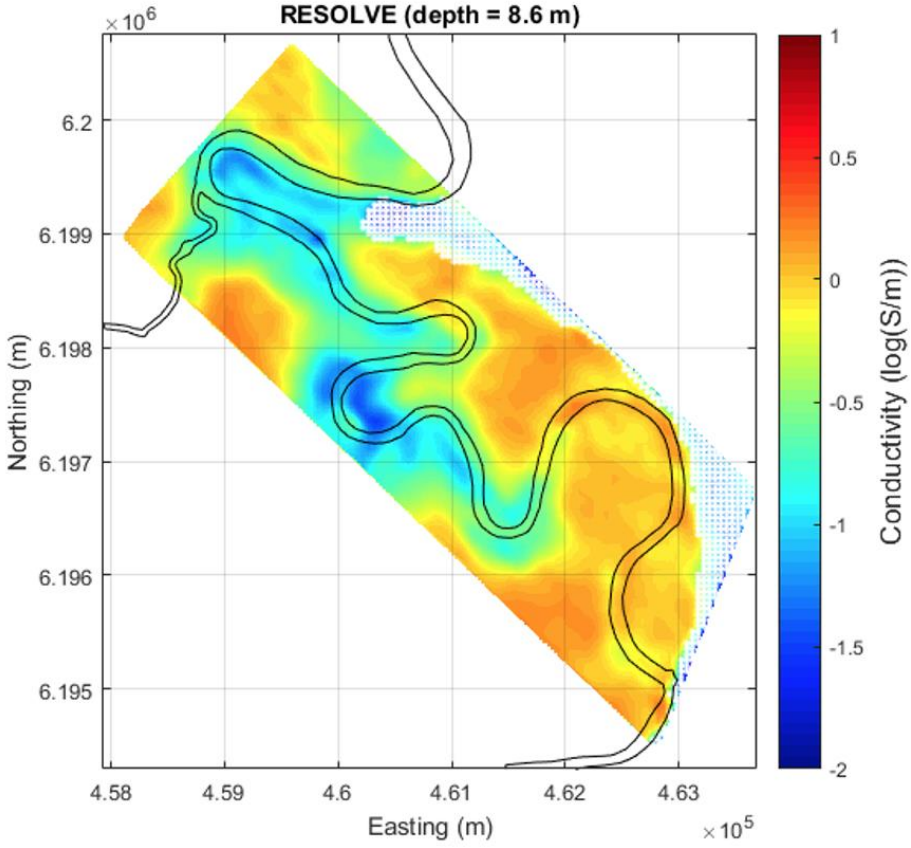
Data



Data fit

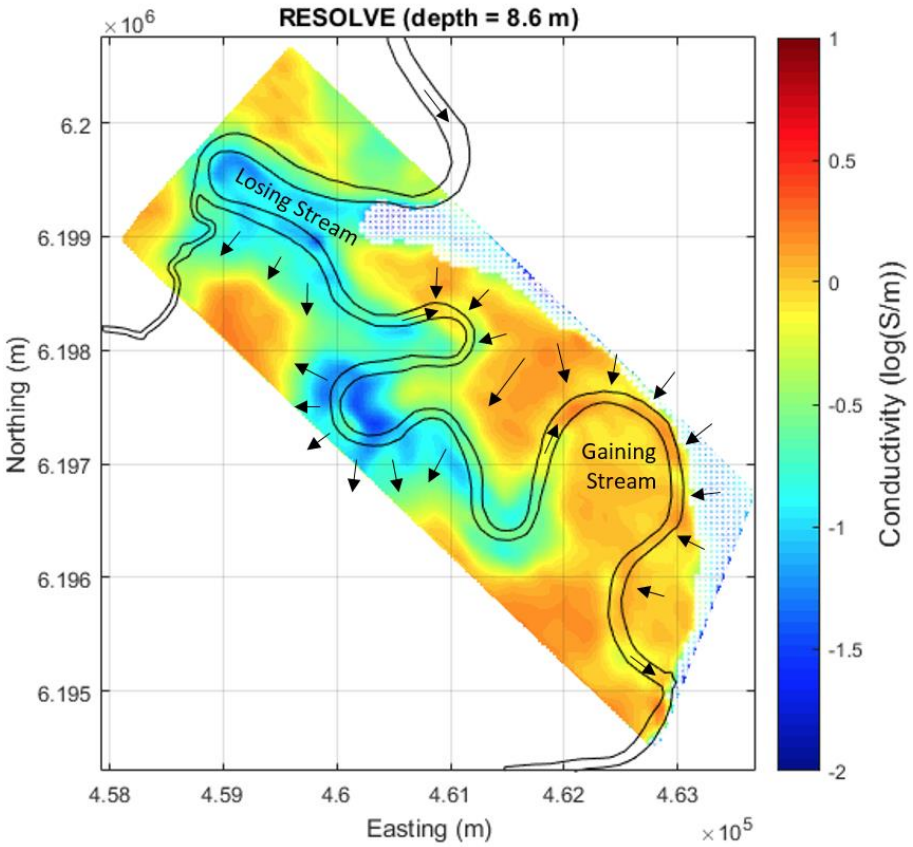


Conductivity model (stitched)

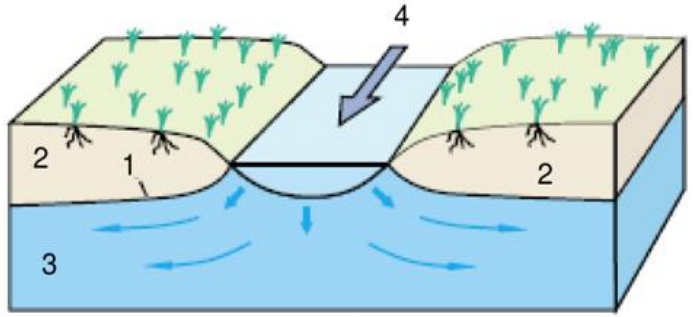


Interpretation

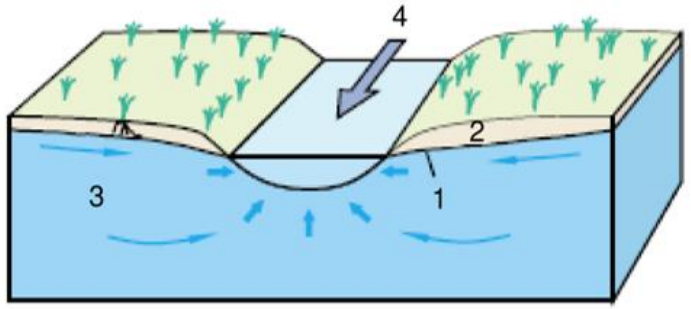
Conductivity model (stitched)



Losing Stream



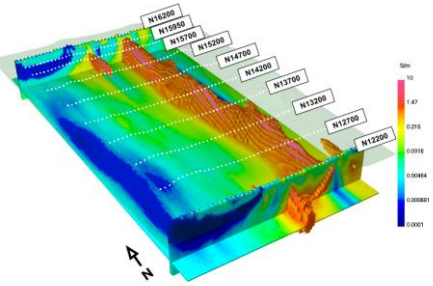
Gaining Stream



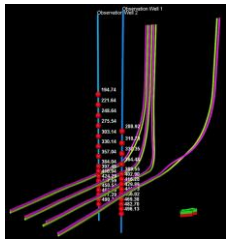
1 – Water table 2 – Unsaturated zone

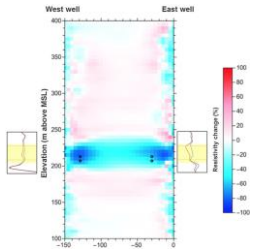
3 – Saturated zone 4 – Flow direction

Case Histories

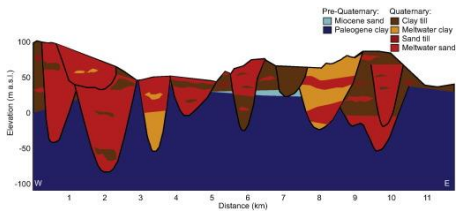


Mt. Isa, Australia: Mineral Exploration

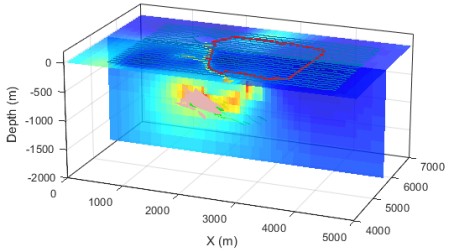




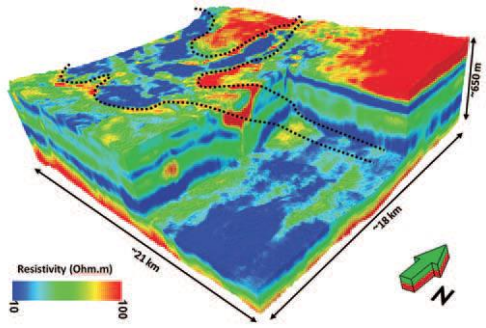
Athabasca Oil Sands, Canada: Monitoring



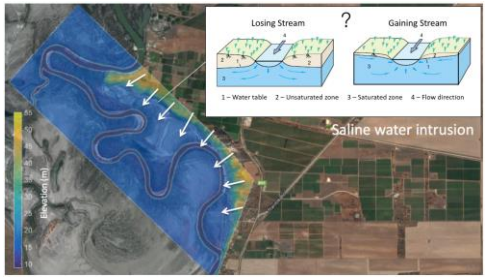
Kasted, Denmark: mapping paleochannels



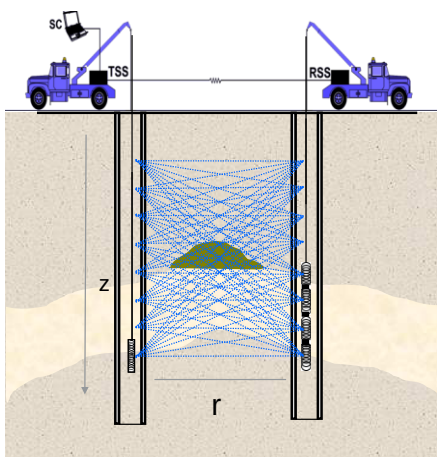
HeliSAM at Lalore: Minerals



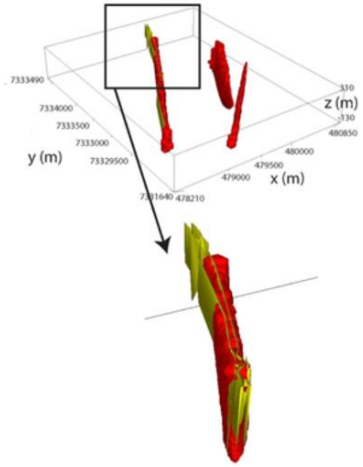
Wadi Sahba, Saudi Arabia: static corrections for seismic



Bookpurnong, Australia: diagnosing river salinization

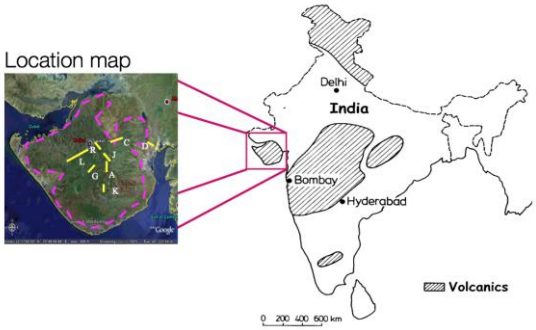


Dom João, Brazil: water flood monitoring

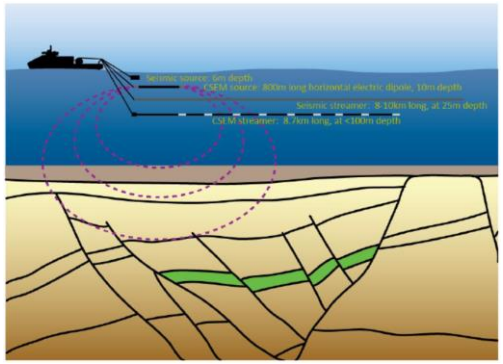


West Plains, Canada: Mineral exploration

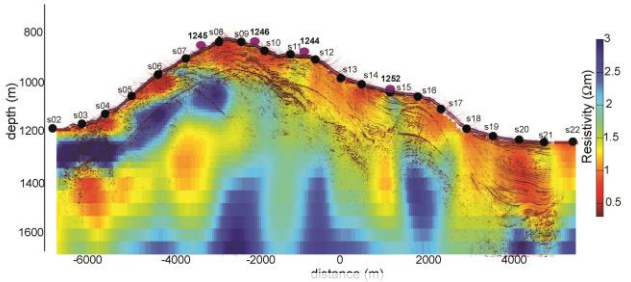
Case Histories



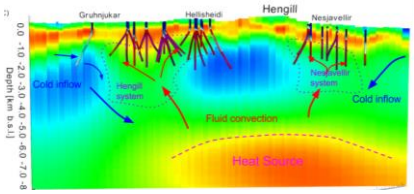
Deccan Traps, India: mapping sediment beneath basalt



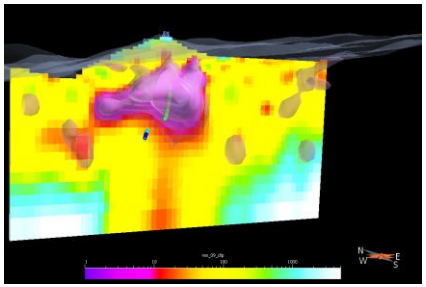
Barents Sea, Norway Hydrocarbon de-risking



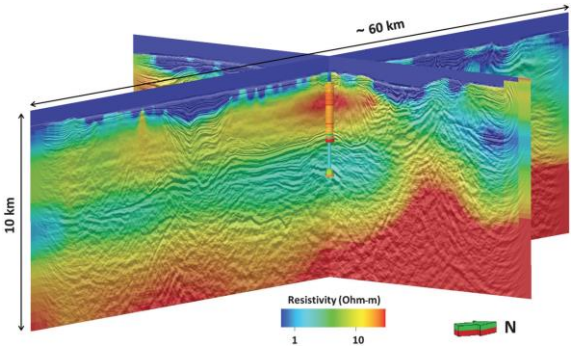
Hydrate Ridge, USA: Marine CSEM



Iceland: characterizing geothermal systems

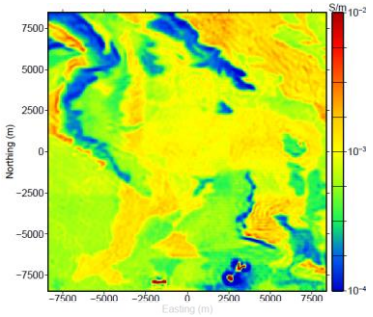


Santa Cecilia, Chile: Mineral Exploration

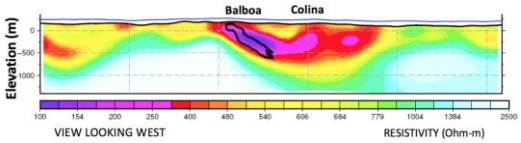


Red Sea: Mapping complex marine geology

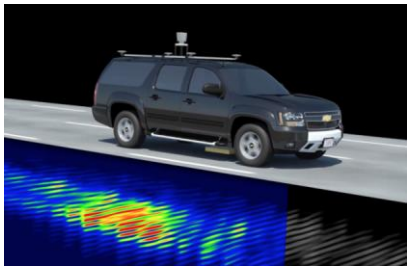
Case Histories



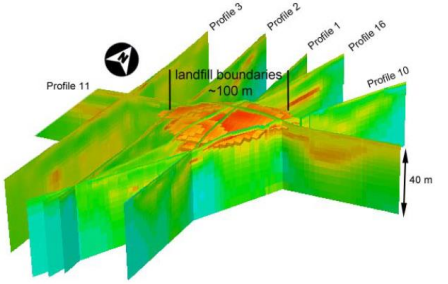
Noranda, Canada:
Geologic Mapping



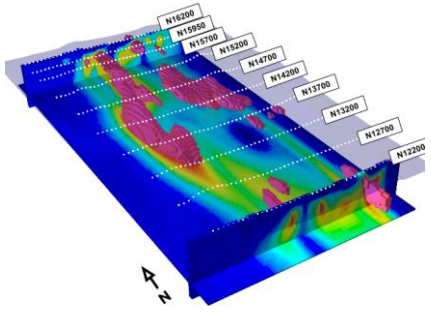
Balboa, Panama:
Mineral Exploration



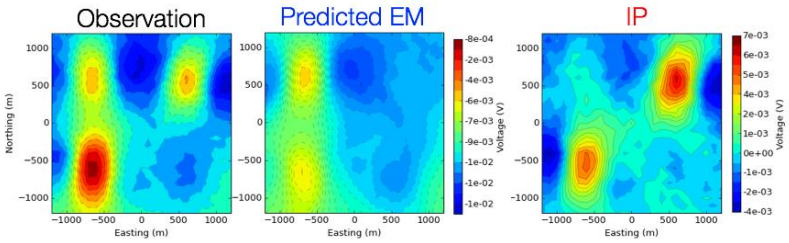
USA: Self-driving
vehicles



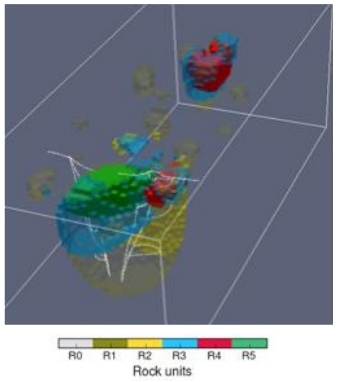
Denmark: IP for
landfills



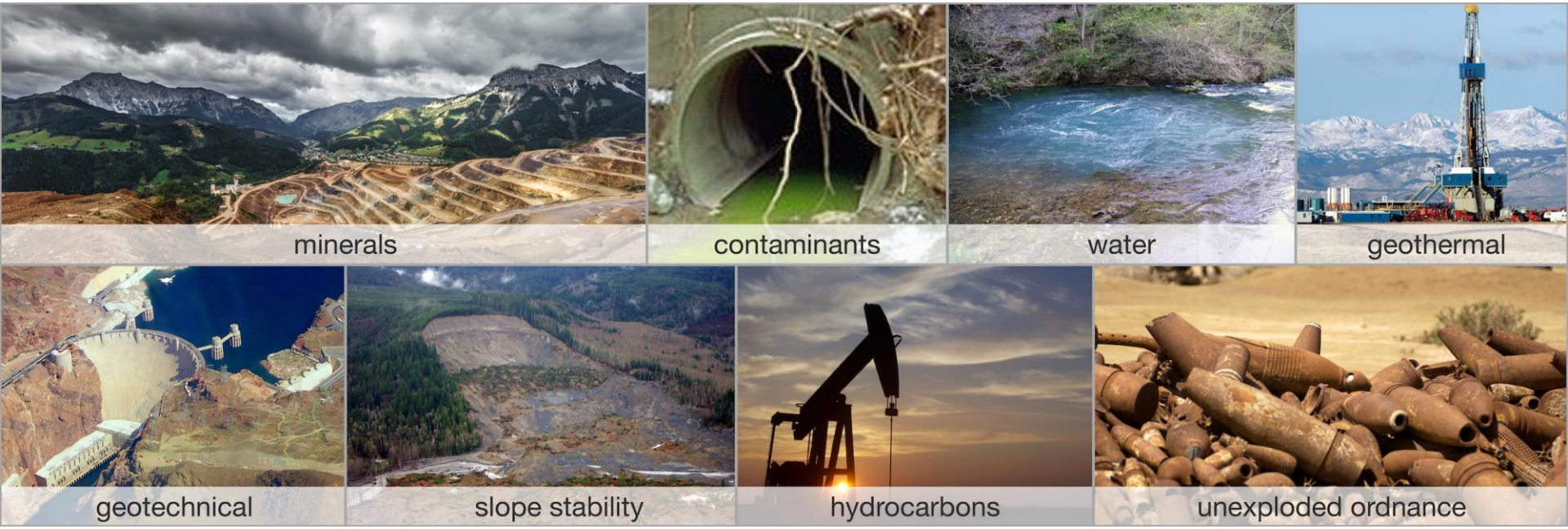
Mt. Isa, Australia:
Mineral Exploration



EM – IP Inversion
(decoupling)



TKC, Canada:
Mineral Exploration



https://em.geosci.xyz/index.html

CourseKey

- An active learning platform that can be used for daily attendance, in-class assessments and polls, asking questions, etc.
- Download the CourseKey app
- To add our class, search for Jiajia Sun, or use the join code ck4003ug.
- 14 days trial period
- $20 for four month, $30 for one year, or $65 for life.

https://portal.thecoursekey.com/courses/4003/attendance

CourseKey GEOL 4397-03 Tue Thu 04:00 pm - 05:30 pm SUPPORT

Attendance | Create Assessment | Send Assessment | Grades | Inbox | Chat | Roster

TAKE ATTENDANCE

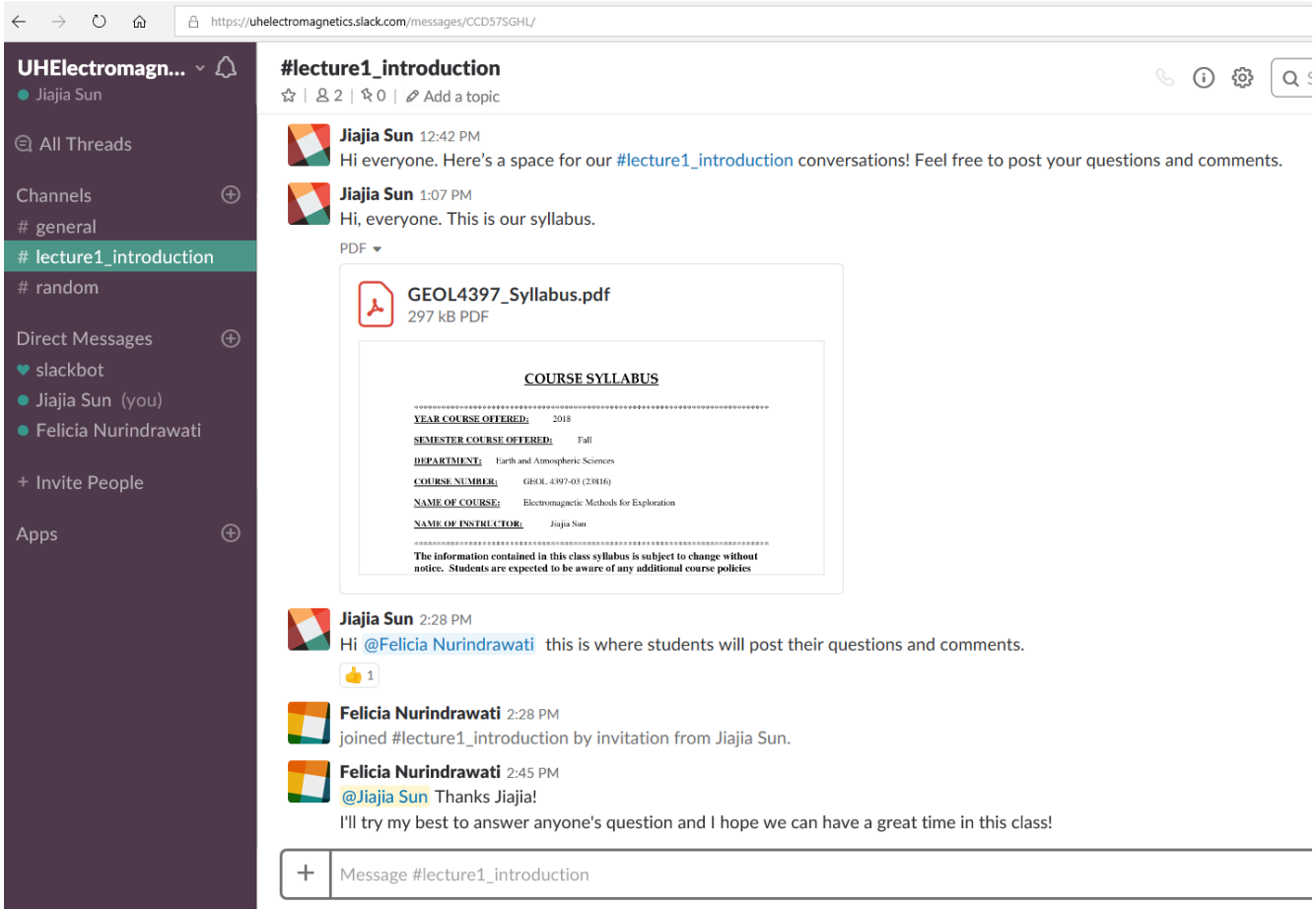
Attendance

Completed | Scheduled

Session	Duration	Check-Ins	Attended	Status	Edit
August 21, 2018 Tue, 04:00 pm - 05:29 pm	04:00 pm - 04:10 pm On Time 04:10 pm - 05:29 pm Late	Check-In 1	0 / 4	Scheduled	
August 23, 2018 Thu, 04:00 pm - 04:30 pm	04:00 pm - 04:10 pm On Time 04:10 pm - 04:30 pm Late	Check-In 1	0 / 4	Scheduled	
August 28, 2018 Tue, 04:00 pm - 04:30 pm	04:00 pm - 04:10 pm On Time 04:10 pm - 04:30 pm Late	Check-In 1	0 / 4	Scheduled	
August 30, 2018 Thu, 04:00 pm - 04:30 pm	04:00 pm - 04:10 pm On Time 04:10 pm - 04:30 pm Late	Check-In 1	0 / 4	Scheduled	
September 4, 2018 Tue, 04:00 pm - 04:30 pm	04:00 pm - 04:10 pm On Time 04:10 pm - 04:30 pm Late	Check-In 1	0 / 4	Scheduled	
September 6, 2018 Thu, 04:00 pm - 04:30 pm	04:00 pm - 04:10 pm On Time 04:10 pm - 04:30 pm Late	Check-In 1	0 / 4	Scheduled	

Slack

- The workplace for this class: UHElectromagnetics



Slack

- The workplace for this class: UHElectromagnetics
- Use this link to join UHElectromagnetics on Slack

https://join.slack.com/t/uhelectromagnetics/shared_invite/enQtNDIwMDMyODA5ODU3LWZjZTY1OTkxM2UxOTIzODU1YzQ1NDJkNTY5NjQyYjRiZGQwNWIxOWIyZDI0NDlmYjg3ZTgzNjVhMGZkNmUwNDc

Resources

- em.geosci.xyz
- Free web-based textbooks

Apps

- Jupyter Notebooks written in Python
- Interactive web application that allows you to create and share documents that contain live code, equations, text, videos and images
- Programing in the browser
- Good for writing codes with accompanying texts, images and even videos.
- All lab exercises are built upon these apps
- We will use Microsoft Azure cloud service to run these apps

Special thanks to


Doug


Seogi


Lindsey

and all SimPEG team members!

Administrative basics

Instructor: Jiajia Sun

- Email: jsun20@uh.edu
- Office: SR1 127A
- Office phone: 713-743-7380
- Office hours: Tues/Thur 2:00-3:30 pm, or by appointments

Course materials/announcements

- Blackboard

Administrative basics

- Both lectures and labs
- Lectures: M 108
- Labs: SR1 230

Week	Date	Topics	Comments
1	08/21 Tues	Lecture: Introduction to electromagnetics	
	08/23 Thur	Lecture: Vector analysis & PDE	
	08/27 Mon		Last day to add a class
2	08/28 Tues	Lecture: static electrical field & DC theory	
	08/30 Thur	Lecture: DC (survey & data)	
3	09/04 Tues	Lecture: DC (applications)	
	09/05 Wed		Last day to drop w/o a grade
	09/06 Thur	Lab: Understanding DC survey and sensitivity	Report due on 09/13 @ 4 PM
4	09/11 Tues	Lecture: complex variables & FFT	
	09/13 Thur	Lecture: review of electrodynamic theory	
5	09/18 Tues	Lecture: RL circuit with DC and AC	
	09/20 Thur	Lecture: RL circuit model of EM induction	
6	09/25 Tues	Lab: RL circuit	Report due on 10/02 @ 4 PM
	09/27 Thur	Lecture: Plane waves in frequency and time domain	
7	10/02 Tues	Lab: plane waves	Report due on 10/09 @ 4 PM
	10/04 Thur	Lecture: Time domain EM (inductive source)	
8	10/09 Tues	Lab: Time domain EM	Report due on 10/16 @ 4 PM
	10/11 Thur	Lecture: Frequency domain EM (inductive source)	
9	10/16 Tues	No class due to SEG annual meeting	
	10/18 Thur	No class due to SEG annual meeting	
10	10/23 Tues	Lab: Frequency domain EM	Report due on 10/30 @ 4 PM
	10/25 Thur	Lecture: Recap & Review	
11	10/30 Tues	Exam	
	11/01 Thur	Lecture: EM_grounded sources	last day to drop a course with a 'W'
12	11/06 Tues	Lecture: EM_grounded sources	
	11/08 Thur	Lab: EM_grounded sources	Report due on 11/15 @ 4 PM
13	11/13 Tues	Lecture: EM_natural sources	
	11/15 Thur	Lecture: EM_natural sources	
14	11/20 Tues	Lab: EM_natural sources	Report due on 11/27 @ 4 PM
	11/22 Thur	No class due to Thanksgiving	
15	11/27 Tues	Final presentation	
	11/29 Thur	Final presentation	
Note	27 Class Meetings		

Grading policy

- Attendance & Involvement: 15%
- Exam: 20%
- Lab exercises + report: 50%
- Final presentation: 15%
- Late policy
  - Lab reports are always due at 4 PM on the seventh day after the lab session
  - Afterwards, 2% off per hour.
- Collaboration policy
  - Read student code book, understand 'collaboration' vs 'infraction'
  - Use your judgement

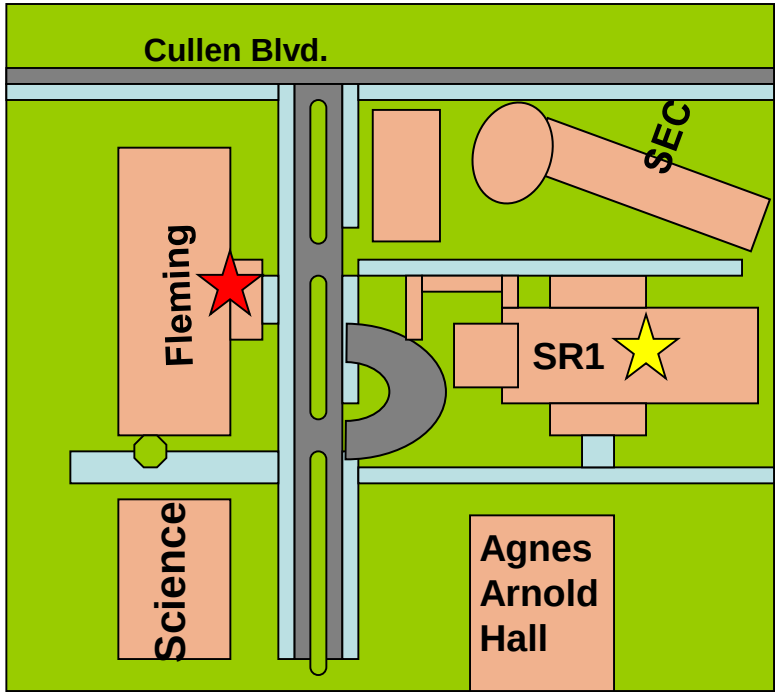
Missed quizzes and make up work

- If you miss a quiz due to unavoidable circumstances (e.g., health, car accidents), inform the instructor as early as possible, and be prepared to provide relevant records (e.g., a note from doctor, policy report)
- No make-up exam except for rare justifiable circumstances.

Teaching Assistant

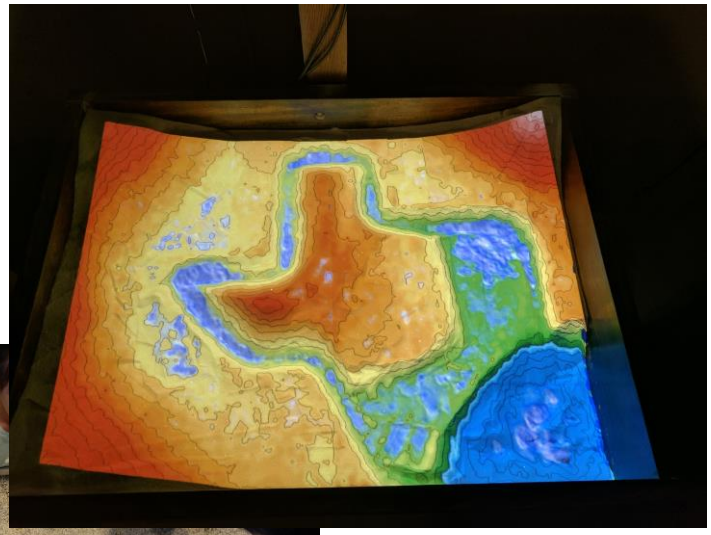
- Felicia Nurindrawati
- 10 am – 12:30 PM on Mondays and Wednesdays
- At GLC

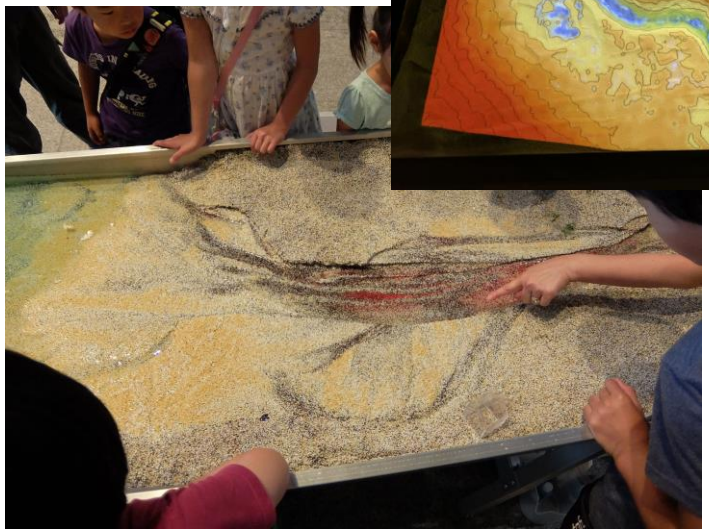
The Geoscience Learning Center (GLC)



GLC

My Office





Coordinators

Dr. Hauptvogel
dwhauptv@central.uh.edu

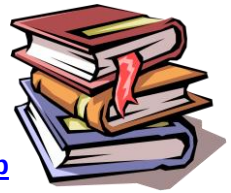
Dr. Sisson
vbsisson@central.uh.edu

Fleming 136

M-Th 8:00am-7:00pm

F 8:00am-6:00pm

Staffed by EAS teaching assistants



geolearn@nsm.uh.edu

713-893-1420

http://www.geosc.uh.edu/undergraduate/learning-center/index.php

One-on-one tutoring - Rocks - Minerals - Textbooks - Augmented Reality Sand Box - River Modeling Table - Microscopes & Thin Sections - Geophysics Workstation - Computers - Study Space - Google Earth - Videos